# STUDIES

# OF

# STABILIZED SOIL-ASPHALT ROAD BASES

By

JAMES C. JOHNSON

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THESIS AND ABSTRACT APPROVED:

J. Rogers Martin
Thesis Adviser

Faculty Representative

Dean of the Graduate School

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As I stand before God, I shall ever strive to be a better engineer: honest, loyal, and trustworthy - - - - a credit to my profession.

James C. Johnson

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## The Problem and Its Scope

### The Problem

The purpose of this report is to present a compilation of the common and currently available information on the subject of soil-asphalt stabilized road bases.

### The Need for This Report

Much of the widely scattered information on soil-asphalt stabilization is uninformative and contradictory, since the science of making roadway mixtures is of relatively recent origin.

A small portion of this information is available in different periodicals and text books, but very few engineers have sufficient information readily available to permit them to work intelligently with these materials.

It is intended that this report will gather sufficient data together in one cover to enable the average engineer to work with confidense on the stabilization of soil-asphalt road bases.

### Delimitations

This report is limited to the soils and the asphalts suitable for soil-asphalt stabilization (with or without additives), some of the additives available to aid proper stabilization, the techniques of laboratory mixing and curing, and some of the laboratory test results of stabilized soil-asphalt mixtures.

No attempt will be made to describe the machinery available for use in the actual construction of stabilized soil-asphalt road bases, except in a very general manner, and even then not designated by name.

No attempt will be made to describe the various possible road surfaces that may be used in conjunction with stabilized soil-asphalt road bases.

Definitions

1. Soil

"The term soil, as used by engineers and as adopted in soil mechanics, covers a much wider range of materials than the same term as used by laymen or as defined by agriculturists and geologists. To the agriculturist, soils is the earth mold within which organic forces are prominent and which is adapted to the support of plant life. To the geologist also, soil is the material in the relatively thin surface zone within which roots occur. According to the broader engineering interpretation, soils are considered to include all earth materials, organic and inorganic, occurring in the zone overlying the rock crust of our planet."[1]

2. Bitumen

"A mixture of native or pyrogenous hydrocarbons and their non-metallic derivatives, which may be gases, liquids, viscous liquids, or solids, and which are soluble in carbon disulphide."[2]

3. Soil Stabilization

"The process of giving natural soils enough abrasive resistance and shear strength to accommodate traffic or loads under prevalent weather conditions without detrimental deformation. The methods employed include the use of admixtures, compaction, and densification by special technical theory and laboratory control. Optimum water content is fundamental with gradation. Admixtures may be soil materials, deliquescent chemicals, solutions of electrolytes, soluble cementitious chemicals, primes and neutralizers, and insoluble binders."[3]

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[1] Donald W. Taylor, Fundamentals of Soil Mechanics, pp. 8-9.

[2] John H. Bateman, Introduction to Highway Engineering, Fifth Edition, p. 166. (as defined by American Society for Testing Materials).

[3] Victor J. Brown, Soil Stabilization, p. 5.

# Chapter II

## The History of Soil and Asphalt

### Soil

Granting that the earth was at one time a ball of flaming rocks and gases, as scientists tell us to be a fact, we must realize that all soils as they exist today are descended in some manner or other from rocks. As the overheated rocks began to cool, there was splitting and cracking of the larger rocks until the size of the particles approached soil dimensions. As time went on, the action of the winds, waves, and abrasive action of flying particles, along with scouring action of moving ice caps, ground more and more rocks to a powder that soon covered the other rocks. As the crust of the earth heaved, buckled, and heaved again, the quantities of soil increased and became widespread. The alternate cycles of freezing and thawing, along with intermittent frost action helped to build up the supply of soil, so that when God placed man upon this earth, the soil was here before him.

### Asphalt

In the same furnaces and deep freeze cycles that promoted the growing supply of soil, oils were compressed, heated excessively under pressure, and pools were formed into which vegetation, animals, and other debris were trapped. Through long ages of changing, collecting of dead bodies, and boiling, burning, and percolating through rocks and minerals of the earth, asphalt took its place of repose in the earth, and on the surface as lakes and rivers of heavy slow-flowing oils, tars, and varying grades of bituminous material.

We have discovered the bones of animals, which no longer inhabit our earth, preserved in, and excavated from, asphalt pits that were here before the advent of mankind.

The first traces that have been found of the use of asphalt by man indicated man used an asphaltic material as an adhesive about 5700 to 5800 years ago (about 3000 B. C.).

We know that a mastic mixture of asphalt, clay, gypsum, and organic matter was used for water-proofing some 5000 years ago (about 3000 B.C.) by pre-historic races in India.

Some 2500 years ago, Nebuchadnezzar (651-604 B.C.), King of Babylon, built houses, walls, and streets of bitumen and burned bricks, some of which are bound tightly together now, despite the ravages of time. Nebuchadnezzar built a sewer, with which to drain the city of Babylon, and lined it with blocks composed of a mixture of asphalt, loam, and gravel. The Inca Indians of Peru constructed an elaborate systems of highways, some of which were paved with a composition not unlike modern bituminous macadam, about 450 to 500 years ago.

It would seem that soil-asphalt stabilization, with or without additives, is an art that has been "re-discovered" after being lost for a number of centuries.

The present day history of soil-asphalt mixtures appears to re-begin about 1900 A. D., at which time a street was constructed in Washington, D. C., of an intimate mixture of a soil and tar compound, covered with chips of stone.

# Chapter III

## Constituents of Soil-Asphalt Stabilized Bases

### Soil

In general, the soils that are considered to be suitable for stabilization with asphalt, and without the use of chemical additives or other admixtures, must be of a granular nature, and must conform approximately to the suggested specifications shown in Table 1.

Table 1

Suggested Specifications[4] for Soils Suitable for Soil-Asphalt Stabilization

| | | |
|---|---|---|
| Percent passing number | 5 sieve | 50 + |
| Percent passing number | 40 sieve | 50 - 100 |
| Percent passing number | 200 sieve | not more than 45 |
| Liquid limit of material passing number | 40 sieve | less than 30 |
| Plastic index of material passing number | 40 sieve | less than 10 |

Some success has been achieved in both the laboratory and the field in ignoring these suggested specifications when certain admixtures were used with the soil to be stabilized.

### Asphalt

There are a number of bituminous products, or grades and types of products, that may be used for the stabilization of different soils. Under normal circumstances liquid asphalts are used for soil stabilization. The liquid asphalt used should meet the specifications of the American Society for Testing Materials for each grade and type of asphalt used in stabilization of road base soils.

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4 George H. Dent, "Stabilization of Soil with Asphalt", American Road Builders' Association, Technical Bulletin No. 164, (1949), 5.

The liquid cut-back asphalts that are considered to be suitable, by the American Road Builders' Association, for soil-asphalt stabilization are shown in Table 2.

Table 2

| Liquid Cut-Back Asphalts for Soil-Asphalt Stabilization[5] |
|---|
| Rapid-Curing Cut-Back, Grades |
| RC-1 |
| RC-2 |
| RC-3 |
| RC-4 |
| Medium-Curing Cut-Back, Grades |
| MC-1 |
| MC-2 |
| MC-3 |
| MC-4 |
| Slow-Curing Cut-Back, Grades |
| SC-1 |
| SC-2 |
| SC-3 |
| SC-4 |

Cut-Back asphalts are the products of asphalt that have been reduced in consistency by the addition of some solvent as a thinning agent.

Rapid-Curing Cut-Back Asphalt = Basic Bitumen + Naptha or Gasoline.

Medium-Curing Cut-Back Asphalt = Basic Bitumen + Kerosene.

Slow-Curing Cut-Back Asphalt = Basic Bitumen + Light End Oils.

Since these different types and grades of asphalt have a cutter-stock that is susceptible to varying degrees of heat, Table 3 is included to show

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[5] Ibid., p. 5.

the safe temperature ranges to which the different asphalts may be heated for use.

Table 3

Safe Heating Ranges for Asphalts Suitable for Soil-Asphalt Stabilization[6]

| Material | Application Temperature |
|---|---|
| RC-1, RC-2, MC-1 | 80 - 150°F |
| MC-2 | 100 - 200°F |
| RC-3 | 125 - 175°F |
| MC-3 | 150 - 200°F |
| MC-4 | 175 - 225°F |
| SC-1 | 80 - 200°F |
| SC-2 | 130 - 200°F |
| SC-3 | 150 - 225°F |

The suggested procedures for the stabilization of soil with asphalt, as described by the American Road Builders' Association in 1949, makes no mention of emulsified asphalts.

A great number of miles of good roads have bases in which emulsified asphalts were successfully used. The Kansas Highway Department has done considerable research with asphalt emulsion, and has decided that it has a definite place in their program of soil-asphalt stabilization of road bases.

Water

The water that is to be used on a soil-asphalt road base must be free from injurious quantities of organic material, acid, alkali, oil, or other deleterious substances.

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6 Ibid, p. 7.

Additives

The additives that may be used in soil-asphalt stabilization may be either dry or liquid. All dry additives, whether powder or lump, should be added to the dry soil on a percentage basis of the dry soil. The liquid additives will generally be mixed into the liquid asphalt as a percentage of the entire asphaltic material; however, in some instances the liquid additive may be added directly to the soil, as in the case of an acid that will serve as a catalyst and act upon some dry additive that has been mixed into the dry soil.

# Chapter IV

## Stabilization Control

### Laboratory Control

To stabilize a soil road-base with asphalt, the soil must be dampened with water either just prior to, or during, the stabilizing process. The soil must be dampened with sufficient water to wet the soil, but the percentage of water required will always be below the optimum moisture for that soil. The water required for proper working conditions will be governed entirely by the grain sizes of the soil being stabilized. Less water is required for a coarse grained sand than for a fine grained sand; less water is required for a sand soil than for a soil having a high percentage of silt or clay.

Laboratory procedure has been developed whereby water is added to the soil in such a quantity as to bring the soil to its "fluff-point", that is the water content that causes the soil to have its maximum bulking-effect due to the large number of void spaces among the grains caused by arching within the structure of the soil.

Since the "fluff-point" is the point where the soil has the maximum void spaces among the soil grains, it is a logical assumption, that has been corroborated by tests, that the asphalt for stabilization should be added to the soil when the soil has been brought to "fluff-point" by the addition of water to the dry soil.

The laboratory must make the decision as to whether asphalt is to be added to the soil for water-proofing purposes only, or whether it is desirable to change the properties of the soil by use of additives such as Portland Cement, hydrated lime, quicklime, gypsum, rosin, salt, calcium chloride, calcium acrylate, sodium thiosulfate, ammonium persulfate, acetic acid, or chemical non-stripping agents, prior to the mixing for water-proofing.

The proper percentage of asphaltic material, the best type and grade of asphaltic material, the percentage of water to reach "fluff-point", and the kind and percentage of additive, or additives, required (if any), can be determined only in the laboratory by the use of experimental mixes using the soil selected for the project and varying the percentages of the additives and asphalts being considered.

After all of the variables have been brought under control by the laboratory, the stabilization of the road base is ready to begin.

Road Control

There are numerous methods for mixing the materials on, or nearby, the road. Some of the possible methods are listed so that their differences may be better understood.

1. Continuous operation, single pass, mobile mixer, that uses soil in place. This machine proportions the correct amounts of soil, water, and asphalt as it moves along the road mixing and spreading the materials.
2. Continuous operation, single pass, mobile mixer, that works the soil from a windrow and proportions the soil, water, and asphalt as it moves along the road.
3. Mobile mixer, that proportions only the soil and asphalt as it mixes. The water must be placed on the soil by the use of trucks, tank wagons, or some vehicle capable of spreading the proper amount of water ahead of the mixer.
4. Road mix by the use of bulldozers, scarifiers, harrows, discing equipment, grader blades, and general farm equipment, along with trucks, or tank wagons, to distribute water and asphaltic material.
5. Continuous operation, stationary batch-plant mixer, where all ingredients must be weighed into a mixing drum. Close control must be

maintained on the weights of all materials and the length of time that is allotted to mixing of the materials. This method is the one most likely to cause lean spots, or rich spots, in the base material. Some segregation is almost certain to take place since the centrally-mixed base material must be hauled from the central plant to the road project. With this type of mixing, the plant operator will soon become relaxed in his job and try to overload his mixer or cut the mixing time to the bare minimum allowable. The stationary mixer is the most efficient method of mixing since the controls are by weights, and not by volumes as in the case of all road mixes.

Inspection Control

Regardless of the mixing method, or machinery, used in the combining of the materials to form a road base of soil, additives, and bitumen, inspection must be maintained on the job to assure proper and thorough mixing, aeration, and compaction. The inspector must be an intelligent person that understands his duties and can faithfully perform such duties, inspections, sampling, and testing as may be required to insure construction as specified by the laboratory.

## Chapter V

## Curing of Soil-Asphalt Mixtures

At the end of the mixing operation, regardless of what type of mixer was used, and irrespective of how well the mixing was done, there is an excess of both moisture and hydrocarbon volatiles in the mixture that must be aerated out in order to get the best compaction. If the moisture and volatiles are not removed by aeration, or some other method of drying, the base will not be stable, and will shove under traffic loadings. It is a rare occasion when too much of the moisture and volatiles are evaporated away, but such cases do exist. If too much of the moisture and volatiles are removed, the base will not set-up and will ravel at the edges and will break under repetitive loading.

Tests can be performed in a matter of a very few hours to determine the moisture and volatiles present in an soil-asphalt mixture. Liquid cut-back asphalts have from fifty percent (50.0%) to twenty percent (20.0%) volatiles, on a volume basis. It is desirable that the volatiles be reduced by aeration, or in some other manner, to the approximate range of one-third to one-fifth (1/3 - 1/5) of the original volatiles present in the asphaltic material.

There is no set percentage, or range of percentages, that may be specified as the quantity of water to aerate, or evaporate, from a soil-asphalt base mixture prior to compaction. When the base is cured and ready to be compacted, the percentage of water present should definitely be less than one-half (1/2) of the percentage of water that was present when the soil was at "fluff-point" conditions prior to the mixing.

Some persons are obstinately of the opinion that the percentage of water and volatiles present at the time of compaction is of no importance, and that it is a waste of about $300.00 to $500.00 per mile to aerate the moisture and volatiles from the soil-asphalt stabilized base mixture prior to compaction.

Samples were taken from existing road bases that had been aerated, as well as those that had not been aerated, and the fallacies of the "no aeration" belief were fully established. In every case where the soil-asphalt stabilized road base had not been aerated, it was found that the road base had failed and disintegrated within 18 months of the date of its compaction or it was in such a state of dis-repair as to require excessive maintenance.

One of the definite advantages of soil-asphalt stabilized road base is the ease with which it may be re-worked. It may be scarified, or broken up in some manner, so that it may be repulverized and re-worked with some type of stabilization machinery. The only total loss in re-working a soil-asphalt base is a part of the money that was spent on the original project.

# Chapter VI

## Field Curing in the Laboratory

In order to duplicate field curing in the laboratory, samples were taken behind a continuous operation, single pass, mobile mixer, in June 1949, on Oklahoma State Highway Number 199. A 1300 foot test section of the road, having three (3) lanes of eight (8) feet each, was chosen east of Marietta, Love County, Oklahoma. Samples were taken over the test section immediately behind the mixing machine in each of the three lanes and after tests were performed on the three samples, they were thoroughly mixed together to form a composite sample. Other samples were taken at different times until the road base was ready to be compacted. Information concerning these samples is shown in Table 4.

By having taken a sample of the soil-asphalt mixture every day, it was a simple matter to determine, in the laboratory, the exact percentage of moisture and volatiles present at any certain time. Knowing the percent of moisture and volatiles that was present when the road base was compacted, the problem became one of working out a laboratory technique that would allow a duplication of the field results in a shorter period of time.

After a series of tests on the composite sample from the three lanes, it was determined that field conditions could be duplicated in the laboratory in the following manner:

"Place 1000 grams of the soil mix to be cured in the pan and place in a 140°F drying oven. The pan must rest on a shelf and not directly on the bottom of the oven. At the end of one hour, remove from the oven and stir for 30 seconds with a spatula or trowel. The stirring should be accomplished by lifting the material on the spatula or trowel and turning it over so that a homogenous mix is obtained throughout the depth of the material in the pan. Replace the pan in the oven.

"At the end of another hour (2 hours total time), repeat the mixing

> operation and again replace the pan in the oven. This operation is to be repeated each hour, until a total of six hours have elapsed from the time the pan was placed in the oven. After the stirring has been performed for the sixth hour, the mix is ready for molding."[7]

This method of laboratory duplication of field results allowed the mixing, curing, and compacting of a sample in less than eight hours, in comparison to approximately 355 hours in the field. This was one day of laboratory work as compared with fifteen days of field work. Such laboratory duplication of field conditions should enable engineers to predict, with accuracy, the reactions and stability of a soil-asphalt road base the very next day after construction begins. If there has been any mistake in the estimates of materials, the final design of the road base, or some error in setting the controls of the mixing machine, it will show up immediately in the laboratory "Prediction Test", and steps may be taken toward correcting the mistakes with the least possible delay.

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[7] J. Rogers Martin, "Procedure for Curing Soil-Asphalt", Soil-Asphalt Bases, (November, 1949), 11.

Table 4

| Field Data for the Development of a Laboratory Curing Method[8] | | |
|---|---|---|
| Sample No. | Date | Remarks |
| | 6-16-49 | Mixing from station 215 to 228 began at 7:30 a.m. |
| 1 | 6-16-49 | Samples taken immediately behind machine in South Lane from 7:30 a.m. to 9:00 a.m. Samples combined to make composite. |
| 2 | 6-16-49 | Samples taken immediately behind machine in Middle Lane from 1:00 p.m. to 2:30 p.m. Samples combined to make composite. |
| 3 | 6-16-49 | Samples taken immediately behind machine in North Lane from 2:45 p.m. to 4:30 p.m. Samples combined to make composite. |
| 4 | 6-16-49 | After material had been windrowed, composite sample was taken at 5:00 p.m. |
| 5 | 6-17-49 | Windrows not moved. Sampled 2:30 p.m. to 3:15 p.m. Temperature, 85 degrees. Wind fairly strong. Clear sky. |
| 6 | 6-18-49 | Sample taken 10:15 a.m. to 11:00 a.m. Temperature, 85 degrees. Fairly strong wind. Cloudy and hazy. |
| 7 | 6-19-49 | Sample taken from 2:30 p.m. to 3:00 p.m. Temperature, 99 degrees. Slightly cloudy sky. No wind. |
| 8 | 6-20-49 | Sample taken from 12:30 p.m. to 1:00 p.m. Temperature, 99 degrees. Clear and hot. |
| 9 | 6-21-49 | Sample taken from 1:00 p.m. to 1:30 p.m. Temperature, 99 degrees. Clear and hot. |
| 10 | 6-22-49 | Sample taken from 2:00 p.m. to 2:30 p.m. Temperature, 98 degrees. Clear and hot. |
| 11 | 6-23-49 | Sample taken 3:00 p.m. to 3:30 p.m. Temperature, 85 degrees. (Light shower in the night). Clear and windy. |
| 12 | 6-24-49 | Sample taken 4:15 p.m. to 4:45 p.m. Temperature, 88 degrees. Light wind. Partly cloudy. |
| 13 | 6-26-49 | Sample taken from 3:30 p.m. to 4:20 p.m. Moved windrow from Sta. 222 + 00 to Sta. 228 + 00. Moved from Rt. to Lt. Temperature, 86 degrees. Strong wind. Sample taken after move. |
| 14 | 6-27-49 | Sample taken from 2:30 p.m. to 3:00 p.m. Windrows moved from Sta. 215 to Sta. 222 + 00. Moved from Rt. to Lt. Temperature, 90 degrees with light wind. Sample taken after move. |
| 15 | 6-28-49 | Sample taken from 1:30 p.m. Temperature, 94 degrees. Partly cloudy with light wind. |
| 16 | 6-29-49 | Sample taken from 1:30 p.m. to 2:15 p.m. Temperature, 90 degrees. |
| 17 | 6-30-49 | Sample taken from 4:30 p.m. to 5:00 p.m. Part of windrow laid and rolled from stations 215 to 228. Partly cloudy. Sample taken from roll pulled out by Patrol as it was being laid. |
| 18 | 7-1-49 | Sample taken just before laying was completed from 3:00 p.m. to 3:30 p.m. Temperature, 96 degrees. Clear and hot. The laying was done in approximately ½-inch lifts. |

[8] J. Rogers Martin, "Development of a Laboratory Curing Method", Soil-Asphalt Bases, (November, 1949), 8-10.

Table 5

| Curing Data for the Development of a Laboratory Curing Method[9] | | | |
|---|---|---|---|
| Sample No. | Elapsed Time in Hours | % Water | % Volatiles |
| 1, 2, 3 | 0 (Plot 1) | 6.60 | 0.720 |
| 4 | 6.5 | 5.50 | 0.700 |
| 5 | 16 | 3.80 | 0.608 |
| 6 | 41 | 4.66 | 0.538 |
| 7 | 69 | 4.66 | 0.610 |
| 8 | 90 | 3.65 | 0.560 |
| 9 | 114 | 3.35 | 0.510 |
| 10 | 140 | 3.48 | 0.480 |
| 11 | 163 | 2.60 | 0.450 |
| 12 | 190 | 1.60 | 0.320 |
| 13 | 238 | 3.20 | 0.450 |
| 14 | 260 | 2.40 | 0.350 |
| 15 | 280 | 2.24 | 0.385 |
| 16 | 310 | 3.30 | 0.385 |
| 17 | 330 | 3.80 | 0.430 |
| 18 | 355 | 2.04 | 0.338 |

[9] J. Rogers Martin, "Development of a Laboratory Curing Method", Soil-Asphalt Bases, (November, 1949), (Graph; page not numbered)

Table 6

| Soil Constants of Soil in Soil-Asphalt Stabilized Base of Oklahoma State Highway Number 199[10] | | |
|---|---|---|
| Liquid Limit | | 18.50 |
| Plasticity Index | | 4.50 |
| Soil Specific Gravity | | 2.51 |
| Percent Coarse Aggregate (+ 2.00 mm.) | | 18.20 |
| Percent Coarse Sand | (2.0 - .42 mm.) | 18.00 |
| Percent Fine Sand | (.42 - .05 mm.) | 50.60 |
| Percent Silt | (.05 - .005 mm.) | 9.10 |
| Percent Clay | (----.005 mm.) | 4.10 |
| Percent Colloids | (----.001 mm.) | -2.10 |
| Soil Classification | | A - 2(0) Sand |

10 J. Rogers Martin, (Extracted from Table No. 3), Soil-Asphalt Bases, (November, 1949), (No page number).

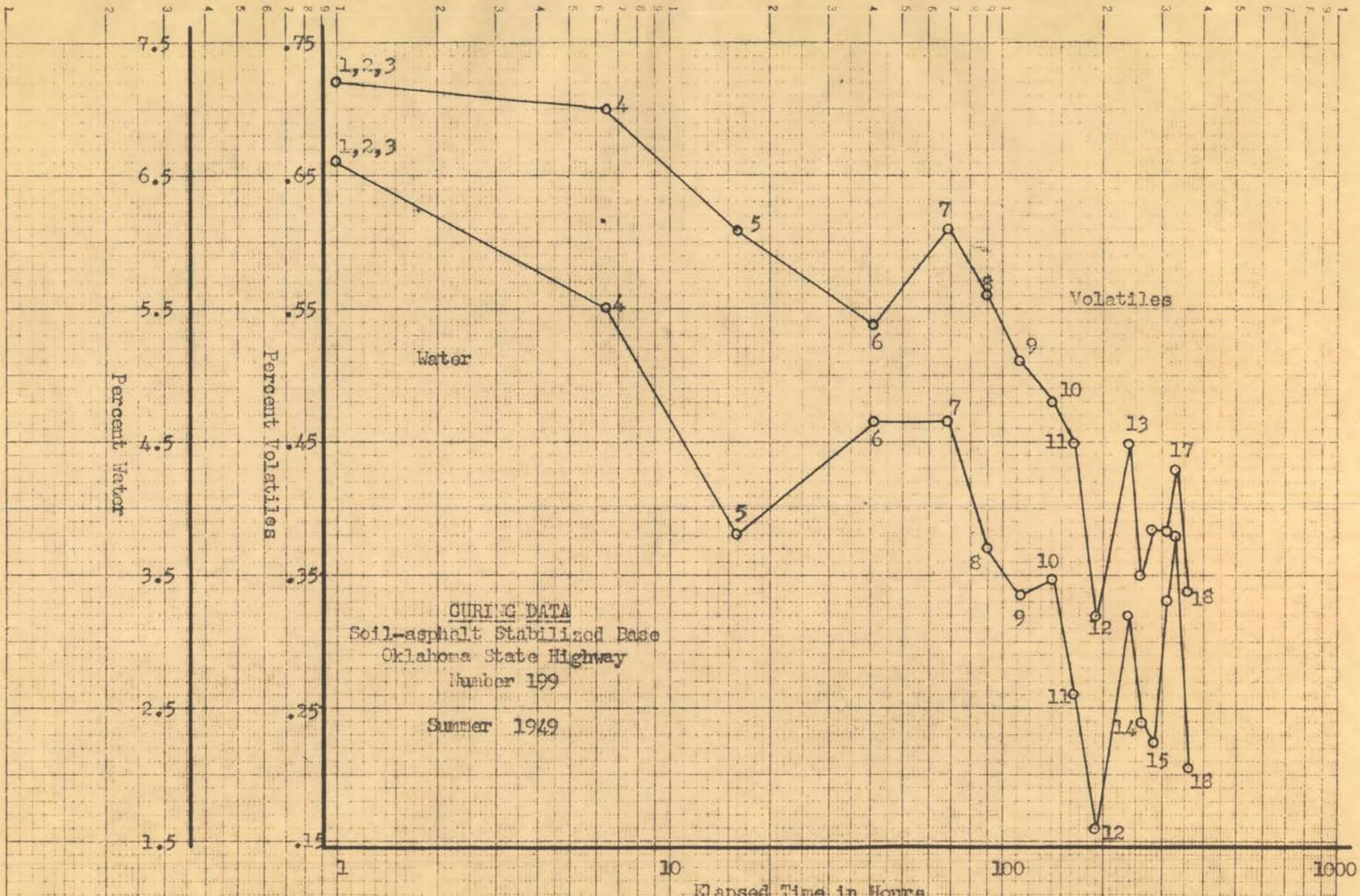
Volatiles
Water
Percent Water
Percent Volatiles
CURING DATA
Soil-asphalt Stabilized Base
Oklahoma State Highway
Number 199
Summer 1949
Elapsed Time in Hours

Fig. No. 1

## Chapter VII

### The Use of Additives on Soils With Plasticity Index Greater Than Ten

On Page Number 5 we spoke briefly of the suggested specifications for soil-asphalt stabilized road bases, and the possibilities of using additives to change the characteristics of the soil to such an extent that they could be stabilized without difficulty. This chapter will bring out more details on these items which are of interest to every highway engineer.

For many years, it has been the expressed opinion of highway engineers in general that time, material, and money was wasted when attempts were made to stabilize a soil having a plasticity index greater than ten, with anything other than sand mixtures. Such thinking has been based on facts and a great deal of negative research until recent years. Even now, the greater amount of the research along this line has been of a negative nature, but a few strides are being made forward in spite of the many steps that lead to negative answers.

Somewhere there is at least one substance that will react with a heavy silt or clay soil and allow its stabilization into a soil-asphalt road base that will be the basic element of a superior road. Engineers are constantly looking for some such material, and some of the research being done gives hope that the present day thinking about soil-asphalt and the soils having plasticity index above ten is in line for some serious revision in the near future.

Twenty-five years ago attempts to stabilize gumbo with lime were failures because there was no machine capable of combining the gumbo soil closely with the lime.[12] Machines are available now that can pulverize and grind the materials together; consequently, unslaked lime is now being used in percentages of from one to ten percent based on dry soil, with startling results.[13]

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[12] Editor, "Stabilizing Gumbo With Lime", Engineering News-Record, (December 29, 1949), 11.

[13] M. G. Spangler, "Soil Stabilization". Engineering News-Record, (December 29, 1949), 16.

The engineers of both the Army and Navy have been doing research on soil stabilization for road bases, airport runways, and landing beaches for heavy equipment. The Navy has developed a machine that will stabilize loose beach sand to carry an 11½ ton truck at the end of 18 hours; however, this test strip rutted-out when a tractor attempted to pull a 25-ton airport pavement tester onto the strip. The Army has developed a rubberized-soil-asphaltic mat that will carry a 25-ton load with impunity.[14] The Army Engineers have stabilized soil by use of 10 percent calcium acrylate, with 1.25 percent sodium thiosulfate catalyst activator, and 1.25 percent ammonium persulfate as the catalystic agent. The cost of calcium acrylate is extremely high because of its limited availability; therefore, it is not apt to become a popularly widespread stabilizing agent for use in soil-asphalt road bases.[15]

Some work has been done on an 11.6 plastic index soil with unslaked lime using acetic acid as a catalyst to start the heating action of the unslaked lime. The heating action of the lime will help evaporate the excess moisture in the mixture. This idea is still in the experimental stage, but some method of putting the acetic acid into the soil immediately prior to the mixing of the asphalt with the soil must be found before the method would have value. It is not desirable that the evaporation of the water and volatiles begin until the asphalt has been thoroughly mixed into the soil; therefore, this combination of additives and catalyst must be investigated more completely before it can be used extensively.

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14 Editor, "Army, Navy Show Off Their Quick-Roads", Engineering News-Record, (November 16, 1950), 30.

15 Editor, "Experimental Soil Solidification", Better Roads, (August, 1950), 39.

## Chapter VIII

## Soil-Asphalt Stabilization of Road Bases in Oklahoma

On January 1, 1951, the State of Oklahoma had six hundred and seven (607) miles of soil-asphalt stabilized road base under traffic. Since the western-half of Oklahoma has a marked lack of road-building stone, but has an over abundance of sand, soil-asphalt mixtures have become increasingly important in the road development program of western Oklahoma.

The oldest soil-asphalt stabilized road base, of which there is a record in Oklahoma, was built in about 1936 on a State Highway, and was in excellent condition in 1949, when it was sampled and tested.

Even though many of our soil-asphalt stabilized road bases have been built longer than ten (10) years, the greater part of them have been constructed since 1946. While most of the older soil-asphalt road bases are in a good state of repair, a number of the bases built in more recent years have disintegrated to such an extent that they are no longer suitable for all types of vehicles.

These road bases in Oklahoma vary in thickness from four to eight (4 - 8) inches. In general, these bases are six to eight (6 - 8) inches thick, according to the type of soil used in the stabilization.

It is desirable that the soil to be stabilized have better than fifty (50) percent sand having angularity. Considerable tolerance may be allowed in the soil gradation. In no case is round grained material, or material of narrow gradation limits desired.

Soil that is to be stabilized should not be a thoroughly washed, or clean, material. Under normal working conditions, a better base will be built if the material to be stabilized has a plasticity index in the range from two to about five (2 - 5 P.I.), while giving all due considerations to the angularity of the particles and the gradation of such particles.

Soil-asphalt stabilized road bases will carry loads and transmit such loads to the subgrade, but these bases will not withstand abrasion; therefore, all stabilized bases of soil-asphalt must have a wearing surface to protect them from the abrasive effect of vehicle tires.

The estimated cost of all maintenance, for 1951, on roads having soil-asphalt stabilized bases was Five Hundred and Twenty-three Dollars ($523.00) per mile. This estimated cost included all expected, or planned, expenditures for base repair, shoulder repair, and patching or resurfacing of the wearing surface. This estimated cost was far lower than the estimated cost for maintenance of any other type of road in the state.

# Chapter IX

## Laboratory Results on Stabilization of Some Oklahoma Soils With Medium-curing Asphalt, Grade Three (MC-3), and Additives

This chapter will present a tabulated and graphical picture of some of the soils found in Oklahoma as they may be used for stabilization purposes with the aid of asphalt and additives. Soils were chosen on both gradation and plasticity index, with the range of plasticity index being the primary consideration. The soils have been classified alphabetically as "Processes," according to the plasticity index.

Comparisons will be made of the soils and the additives used, with special consideration being given to one soil having a plasticity index greater than ten.

| Process Number | Plastic Index | Liquid Limit | Specific Gravity | Rock +2.0 MM | Coarse Sand 2.0-.42MM | Fine Sand .42-05MM | Silt .05-.005 MM | Clay -005 MM | Colloids -001MM | Soil Class | Optimum Moisture | Percent Moisture at "Fluff-Point" |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.0 | 18.0 | 2.45 | 0.0 | 18.8 | 76.7 | 2.5 | 3.0 | 0.0 | A-3(0) | 7.5 | 3.276 |
| B | 0.0 | 22.0 | 2.49 | 0.0 | 0.4 | 91.5 | 4.2 | 3.9 | 1.3 | A-2-3(0) | 14.0 | 3.776 |
| C | 2.2 | 22.5 | 2.65 | 0.0 | 0.2 | 67.6 | 19.1 | 13.1 | 7.7 | A-4(2) | 13.0 | 8.760 |
| D | 4.1 | 21.8 | 2.55 | 0.0 | 1.2 | 73.1 | 9.8 | 15.9 | 9.1 | A-2(0) | 12.8 | 9.940 |
| E | 11.6 | 27.1 | 2.53 | 0.0 | 0.4 | 51.7 | 27.1 | 20.8 | 10.0 | A-6(6) | 13.4 | 10.930 |
| F | 15.9 | 36.0 | 2.59 | 0.0 | 0.4 | 22.9 | 45.0 | 31.7 | 14.2 | A-6(10) | 19.0 | 18.200 |

Table 7

Data On Soils Used In Research

Table 8

Dry Hveem Stabilities of Different Soils and Additive Mixtures With Varying Asphalt Contents

| Process Number | Percent Asphalt | No Additive | 3% Lime | 3% Gypsum | 1% Nostrip |
|---|---|---|---|---|---|
| A | 2 | ----- | 17.00 | 17.75 | 13.00 |
| A | 3 | ----- | 20.75 | 19.25 | 14.00 |
| A | 4 | 14.75 | 19.50 | 18.25 | 13.25 |
| A | 5 | 10.00 | 15.75 | 19.25 | 12.00 |
| A | 6 | 13.25 | 15.75 | 16.00 | 10.00 |
| A | 7 | 14.25 | 17.00 | 19.00 | 8.00 |
| B | 2 | 19.75 | 30.50 | 26.00 | 20.25 |
| B | 3 | 21.50 | 20.00 | 24.25 | 20.75 |
| B | 4 | 18.75 | 19.50 | 25.00 | 19.75 |
| B | 5 | 19.00 | 25.00 | 24.75 | 18.50 |
| B | 6 | 18.25 | 24.50 | 23.75 | 18.75 |
| B | 7 | 15.50 | 22.50 | 21.25 | 17.00 |
| C | 2 | 48.75 | 58.25 | 50.50 | 46.75 |
| C | 3 | 40.50 | 53.50 | 50.75 | 42.50 |
| C | 4 | 36.75 | 54.75 | 45.75 | 40.25 |
| C | 5 | 36.75 | 47.50 | 41.50 | 39.00 |
| C | 6 | 32.25 | 49.00 | 37.75 | 33.50 |
| C | 7 | 30.00 | 49.00 | 35.25 | 31.25 |
| D | 2 | 43.25 | 44.50 | 46.75 | 40.50 |
| D | 3 | 41.50 | 40.00 | 43.00 | 38.75 |
| D | 4 | 35.50 | 39.50 | 41.75 | 35.50 |
| D | 5 | 34.75 | 37.50 | 39.00 | 30.75 |
| D | 6 | 34.25 | 41.50 | 33.75 | 30.25 |
| D | 7 | 33.00 | 39.00 | 35.25 | 29.75 |
| E | 2 | 72.00 | 72.50 | 73.25 | 76.00 |
| E | 3 | 68.00 | 75.50 | 74.50 | 72.75 |
| E | 4 | 67.75 | 74.50 | 69.75 | 67.50 |
| E | 5 | 60.50 | 73.50 | 65.50 | 60.25 |
| E | 6 | 55.25 | 68.75 | 63.75 | 54.75 |
| E | 7 | 52.00 | 59.25 | 60.00 | 47.50 |
| F | 2 | 78.25 | 76.75 | 80.50 | 80.25 |
| F | 3 | 77.00 | 76.25 | 77.25 | 74.00 |
| F | 4 | 74.00 | 73.50 | 76.50 | 73.25 |
| F | 5 | 71.50 | 74.50 | 74.50 | 70.50 |
| F | 6 | 73.50 | 73.50 | 66.25 | 64.00 |
| F | 7 | 60.00 | 67.50 | 62.25 | 59.75 |

Table 9

Percent Moisture Absorbed in Hveem Stability Specimens
(Seven Days Immersion Soaking)

| Process Number | Percent Asphalt | No Additive | 3% Lime | 3% Gypsum | 1% Nostrip |
|---|---|---|---|---|---|
| A | 2 | 16.40 | 1.30 | 12.60 | 17.10 |
| A | 3 | 14.00 | 0.70 | 10.00 | 14.10 |
| A | 4 | 12.1 | 0.60 | 8.00 | 10.30 |
| A | 5 | 13.50 | 0.60 | 8.60 | 11.60 |
| A | 6 | 12.40 | 0.60 | 6.20 | 10.30 |
| A | 7 | 9.60 | 0.60 | 6.50 | 7.70 |
| B | 2 | 14.00 | 5.50 | 21.10 | 21.30 |
| B | 3 | 19.40 | 1.70 | 20.00 | 14.00 |
| B | 4 | 13.60 | 0.90 | 10.70 | 9.40 |
| B | 5 | 11.40 | 1.40 | 10.70 | 6.70 |
| B | 6 | 10.70 | 1.10 | 9.70 | 7.80 |
| B | 7 | 11.30 | 1.00 | 6.30 | 9.50 |
| C | 2 | ----- | ----- | ----- | ----- |
| C | 3 | 19.40 | 13.10 | ----- | 20.10 |
| C | 4 | 17.60 | 10.60 | 18.60 | 18.50 |
| C | 5 | 16.10 | 4.00 | 17.30 | 16.90 |
| C | 6 | 9.60 | 2.80 | 16.40 | 13.10 |
| C | 7 | 6.80 | 2.30 | 12.70 | 7.60 |
| D | 2 | 21.55 | 13.80 | ----- | ----- |
| D | 3 | 19.00 | 9.40 | ----- | 19.00 |
| D | 4 | 13.60 | 5.00 | 15.20 | 10.40 |
| D | 5 | 7.10 | 3.10 | 12.60 | 7.30 |
| D | 6 | 4.30 | 2.00 | 7.80 | 6.00 |
| D | 7 | 5.90 | 1.70 | 5.80 | 2.80 |
| E | 2 | ----- | ----- | ----- | ----- |
| E | 3 | ----- | ----- | ----- | ----- |
| E | 4 | ----- | ----- | ----- | ----- |
| E | 5 | ----- | 15.10 | ----- | ----- |
| E | 6 | ----- | 7.70 | ----- | ----- |
| E | 7 | ----- | 4.95 | ----- | ----- |
| F | No specimens of process F survived the 7 day period of soaking. | | | | |

Table 10

Hveem Stability Comparison of Lime and Gypsum Additives
in Soil-Asphalt Mixtures

First Number = Percent of Additive. Letters "L" and "G" = Lime and Gypsum.
1 = 24 Hours Air Cure; 2 = 24 Hours Air Cure Plus 7 Days Capillary Soaking;
3 = 24 Hours Air Cure Plus 7 Days Immersion Soaking.

| Specimen | 4% Asphalt | 7% Asphalt | 10% Asphalt |
|---|---|---|---|
| 3L1 | 74.50 | 59.25 | 49.25 |
| 3L2 | ——— | ——— | 39.00 |
| 3L3 | ——— | 41.75 | 31.00 |
| 5L1 | 76.75 | 58.50 | 54.25 |
| 5L2 | 13.25 | 18.50 | 43.00 |
| 5L3 | 11.50 | 19.50 | ——— |
| 7L1 | 74.50 | 70.00 | 68.00 |
| 7L2 | 12.25 | 33.25 | 60.75 |
| 7L3 | ——— | 29.50 | 52.50 |
| 10L1 | 74.50 | 71.25 | 67.50 |
| 10L2 | 18.75 | 39.25 | 62.50 |
| 10L3 | 13.50 | 28.00 | 45.50 |
| 3G1 | 69.75 | 60.00 | 35.00 |
| 3G2 | ——— | ——— | 10.00 |
| 3G3 | ——— | ——— | ——— |
| 5G1 | 77.25 | 67.50 | 35.75 |
| 5G2 | ——— | 31.00 | ——— |
| 5G3 | ——— | ——— | ——— |
| 7G1 | 79.00 | 56.50 | 37.00 |
| 7G2 | ——— | ——— | ——— |
| 7G3 | ——— | ——— | ——— |
| 10G1 | 76.50 | 50.00 | 33.50 |
| 10G2 | ——— | ——— | ——— |
| 10G3 | ——— | ——— | ——— |
| NA1 | 68.50 | 54.50 | 34.00 |
| NA2 | ——— | 21.00 | 17.75 |
| NA3 | ——— | ——— | ——— |

Hveem Stability Comparison of Soils

Letters Indicate Process Numbers

No Additive

24 Hours Air-cured

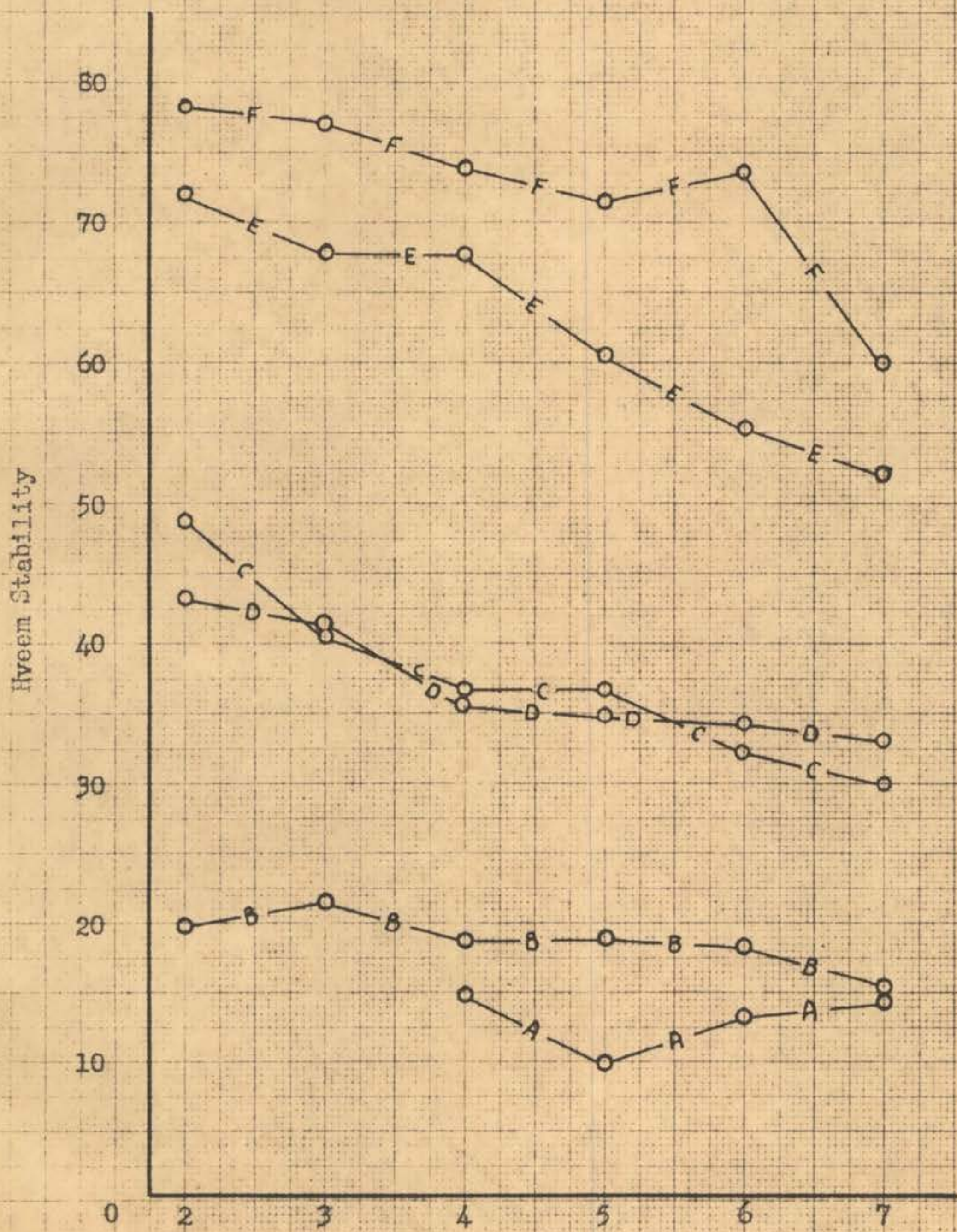


Fig. 2. Percent MC-3 Asphalt

Hveem Stability Comparison of Soils

Letters Indicate Process Numbers

24 Hours Air-cured, 7 Days Immersion Soak

No Additive

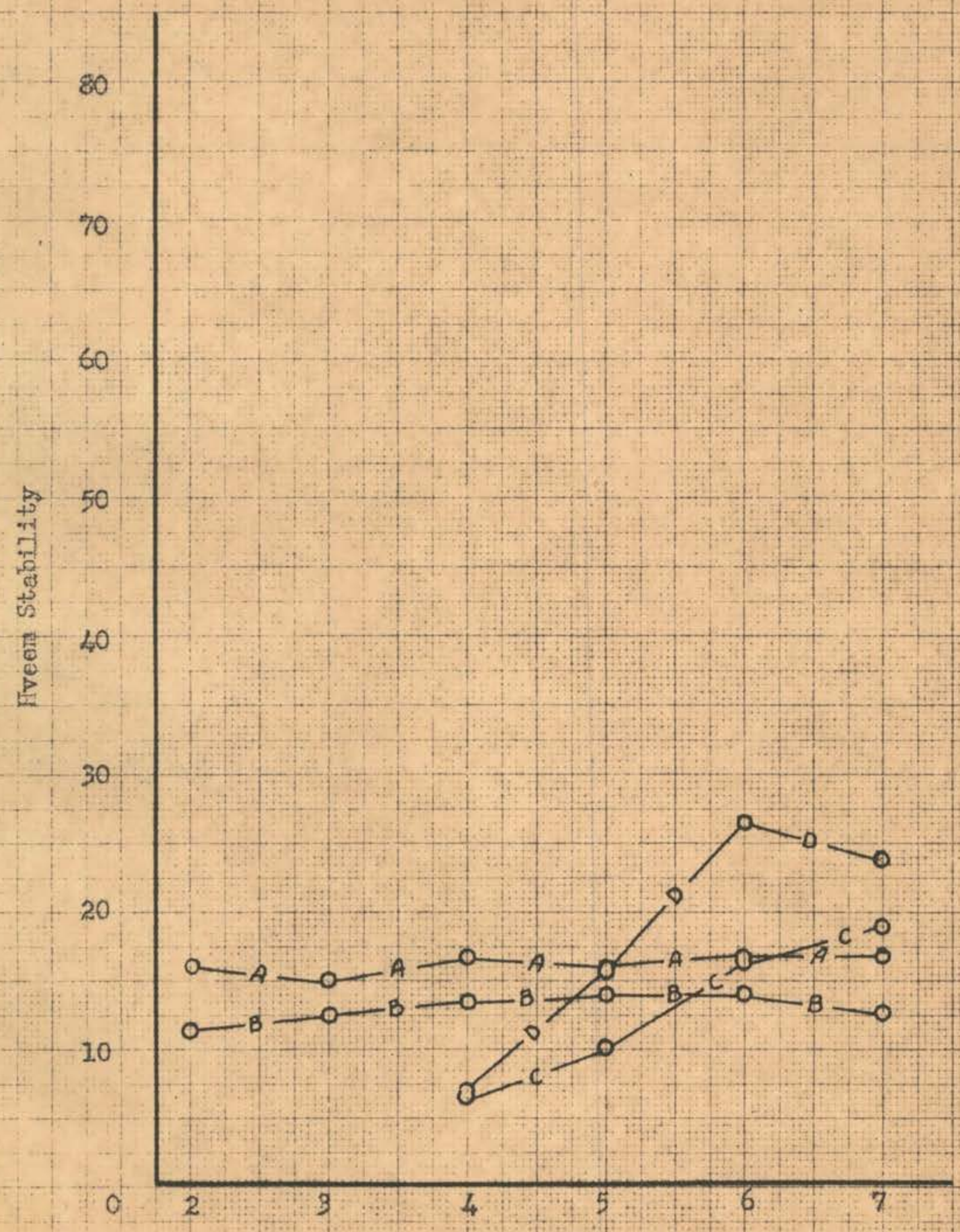


Fig. 3. Percent MC-3 Asphalt

Hveem Stability Comparison of Soils

Letters Indicate Process Numbers

3% Lime Additive

24 Hours Air-cured

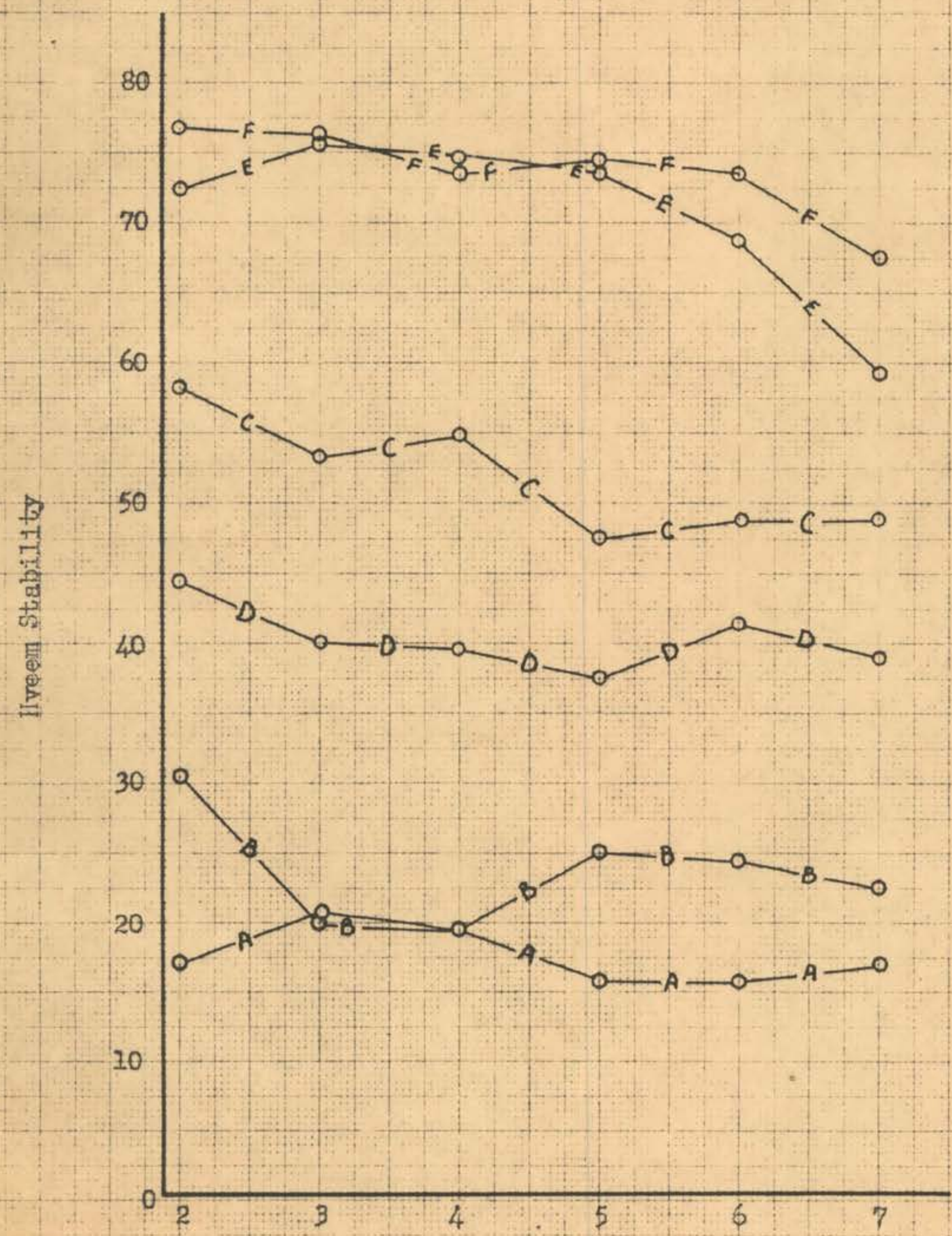


Fig. 4. Percent MC-3 Asphalt

Hveem Stability Comparison of Soils

Letters Indicate Process Numbers

24 Hours Air-cured, 7 Days Immersion Soak

3% Lime Additive

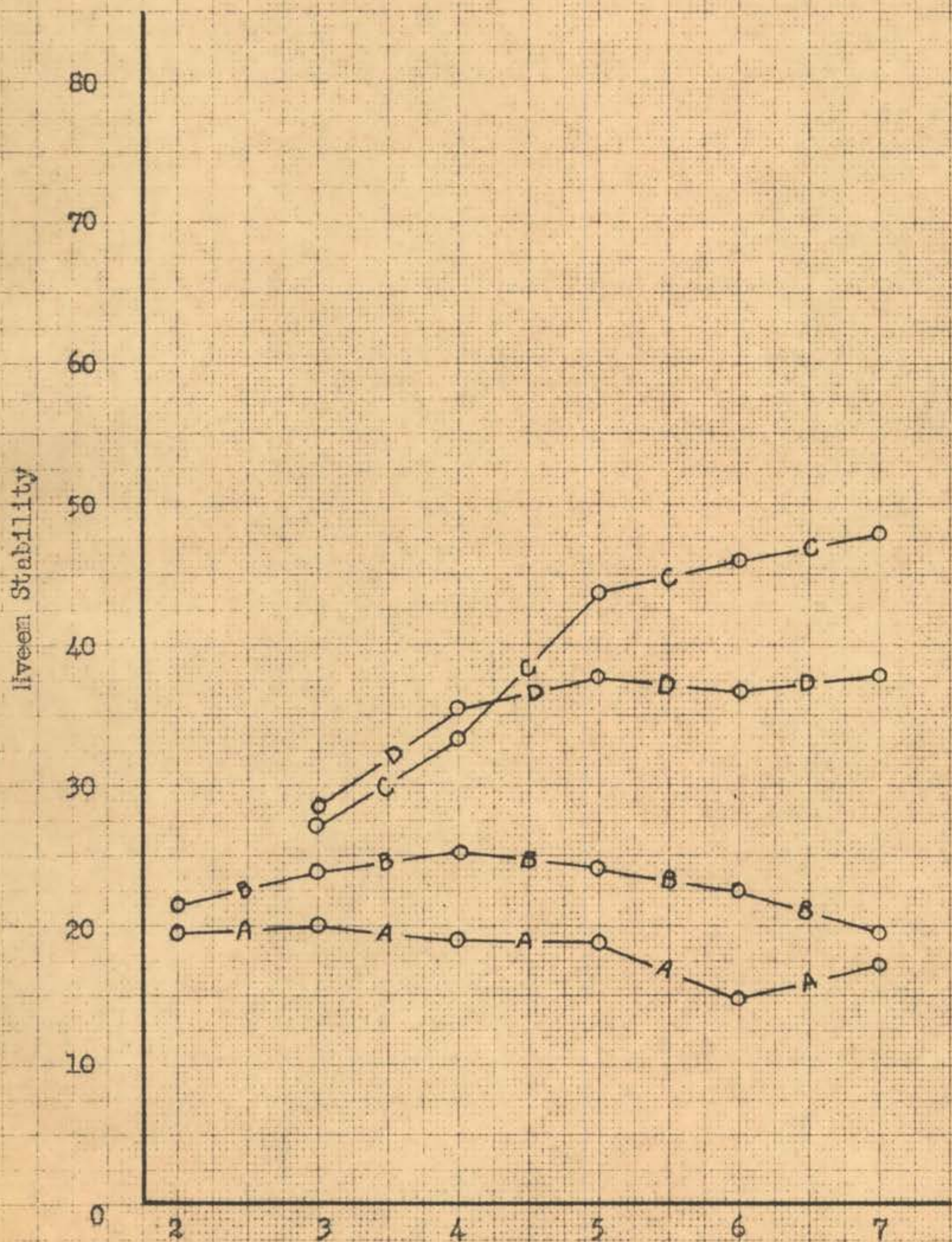


Fig. 5. Percent MC-3 Asphalt

Hveem Stability Comparison of Soils

Letters Indicate Process Numbers

24 Hours Air-cured

3% Gypsum Additive

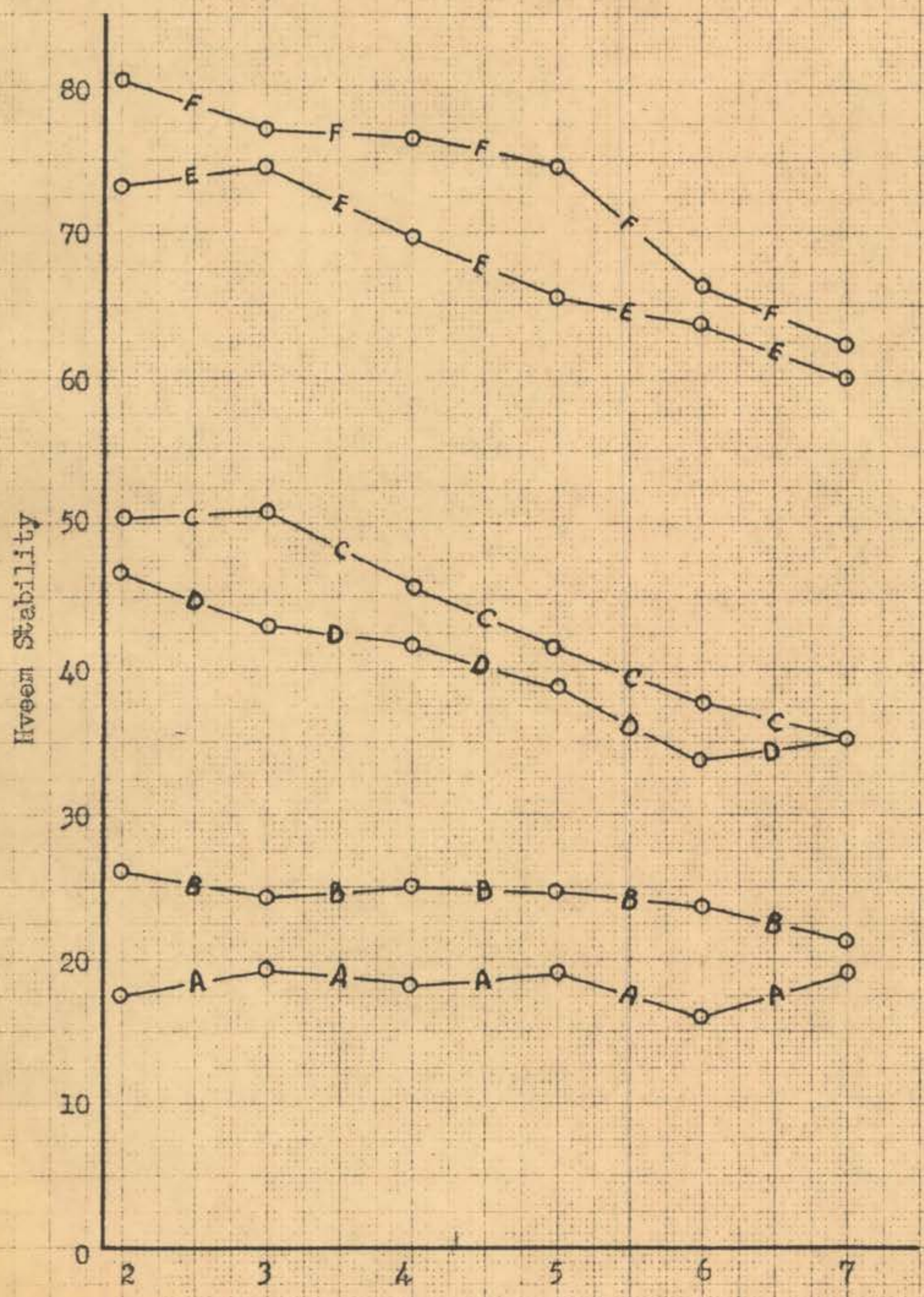


Fig. 6. Percent MC-3 Asphalt

Hveem Stability Comparison of Soils

Letters Indicate Process Numbers

24 Hours Air-cured, 7 Days Immersion Soak

3% Gypsum Additive

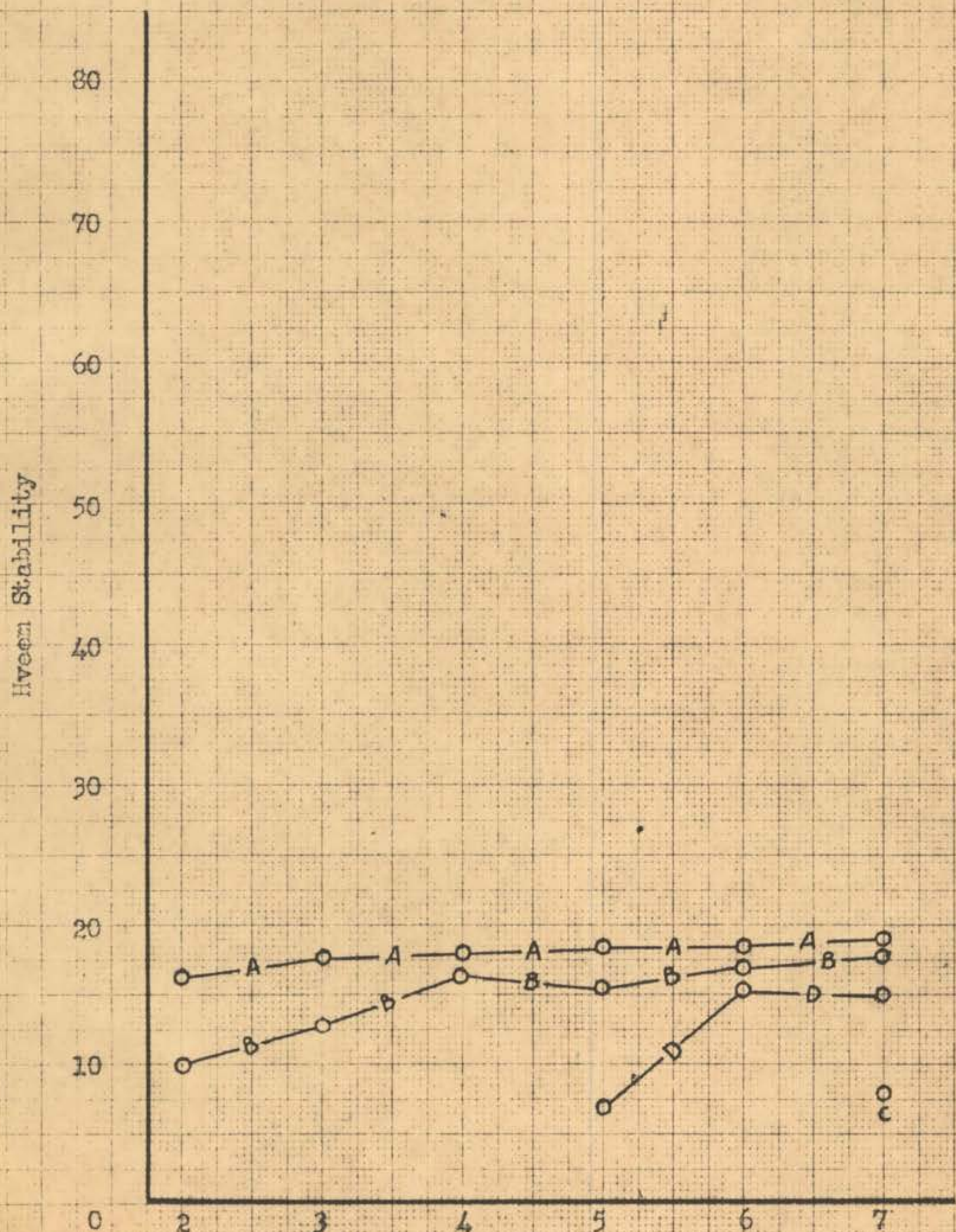


Fig. 7. Percent MC-3 Asphalt

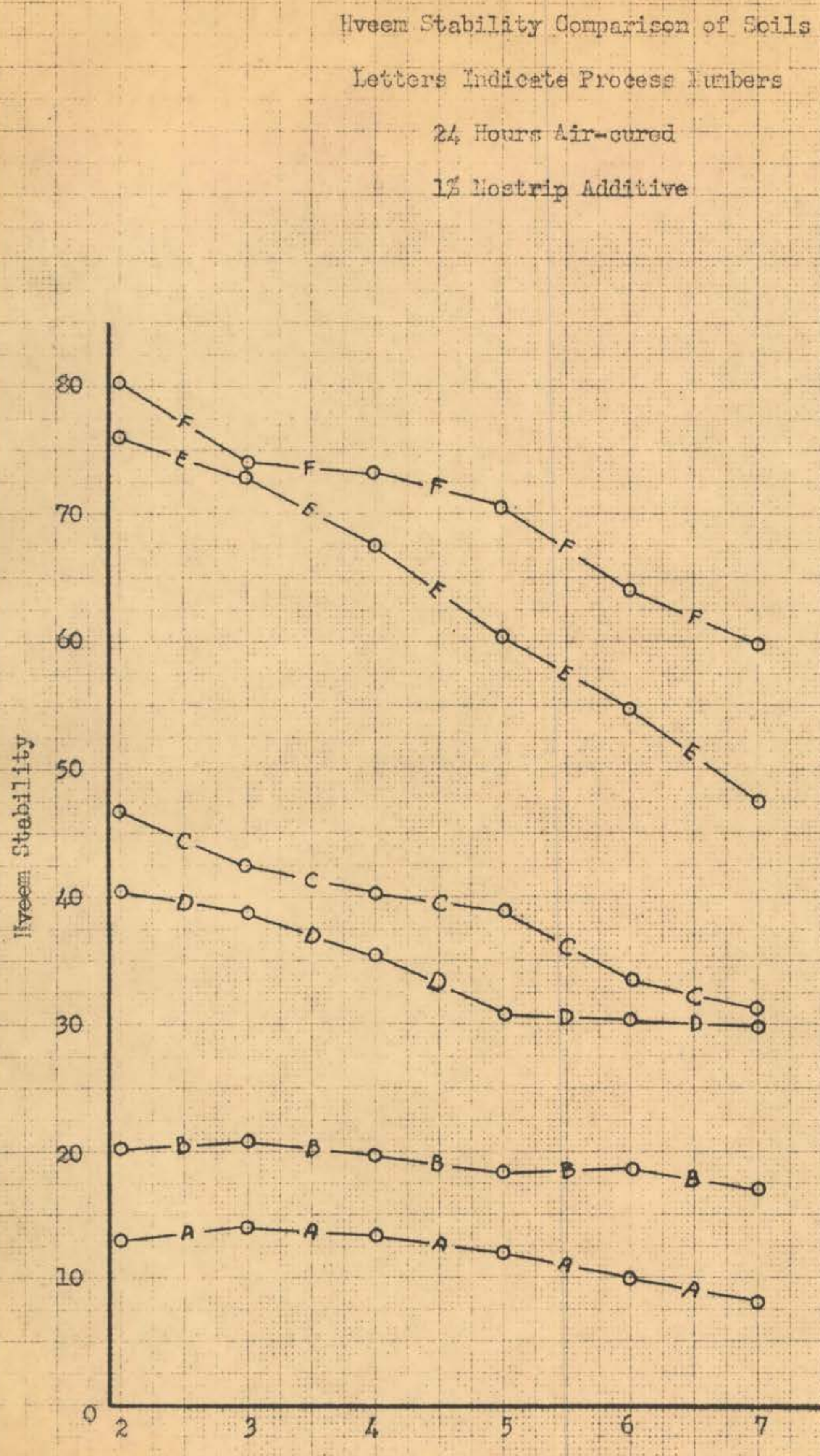


Fig. 8. Percent MC-3 Asphalt

Hveem Stability Comparison of Soils

Letters Indicate Process Numbers

24 Hours Air-cured, 7 Days Immersion Soak

1% Nostrip Additive

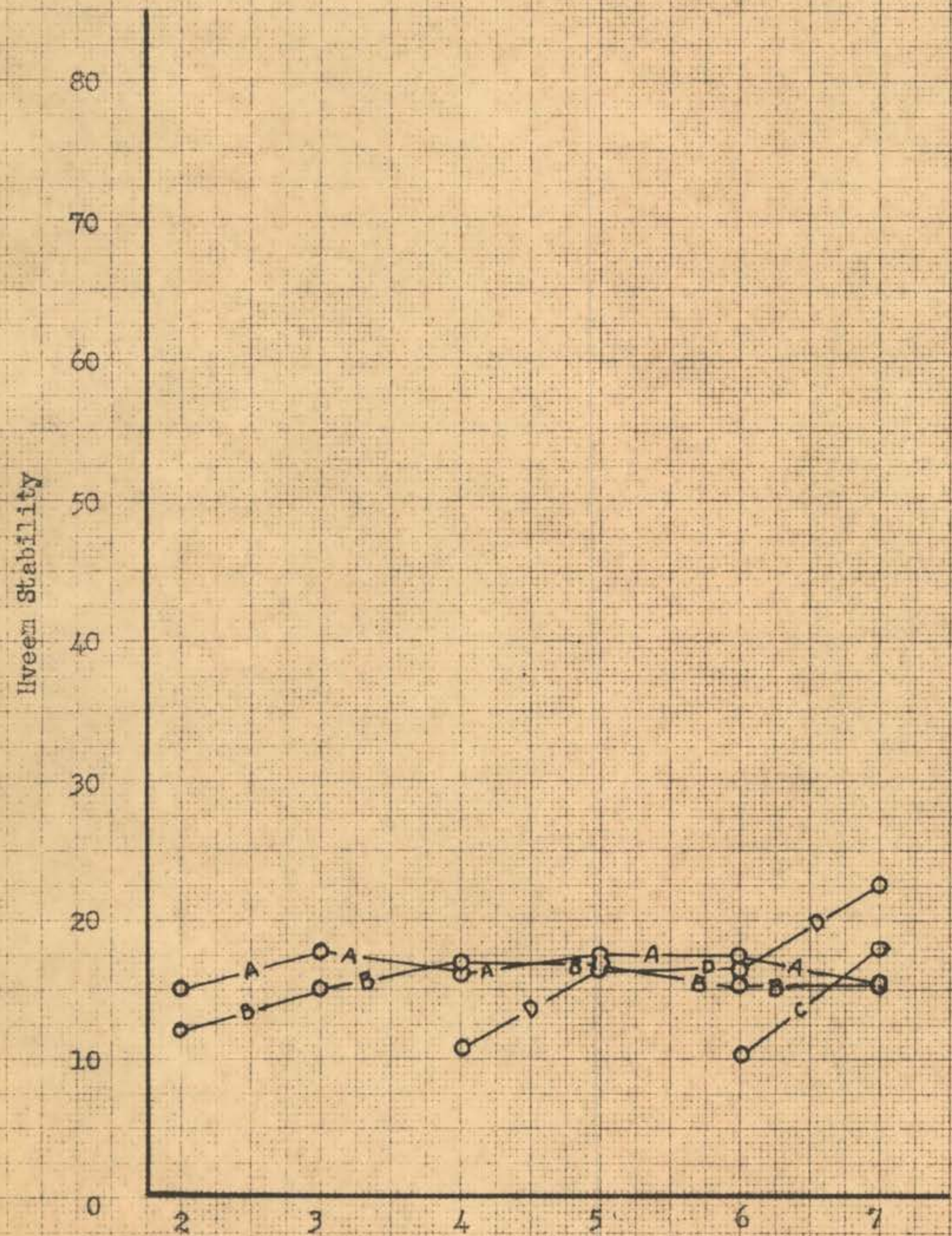


Fig. 9. Percent MC-3 Asphalt

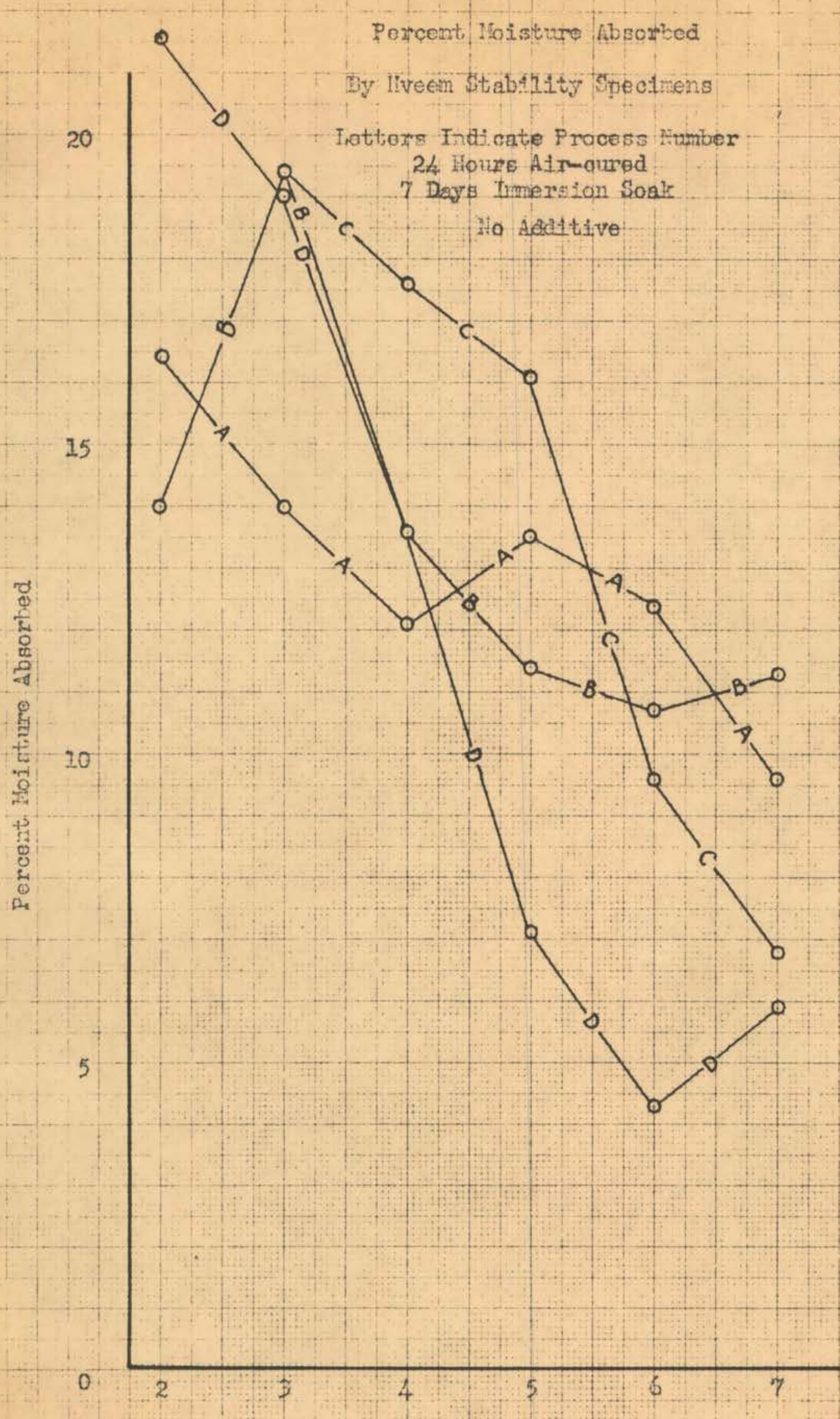


Fig. 10. Percent MC-3 Asphalt

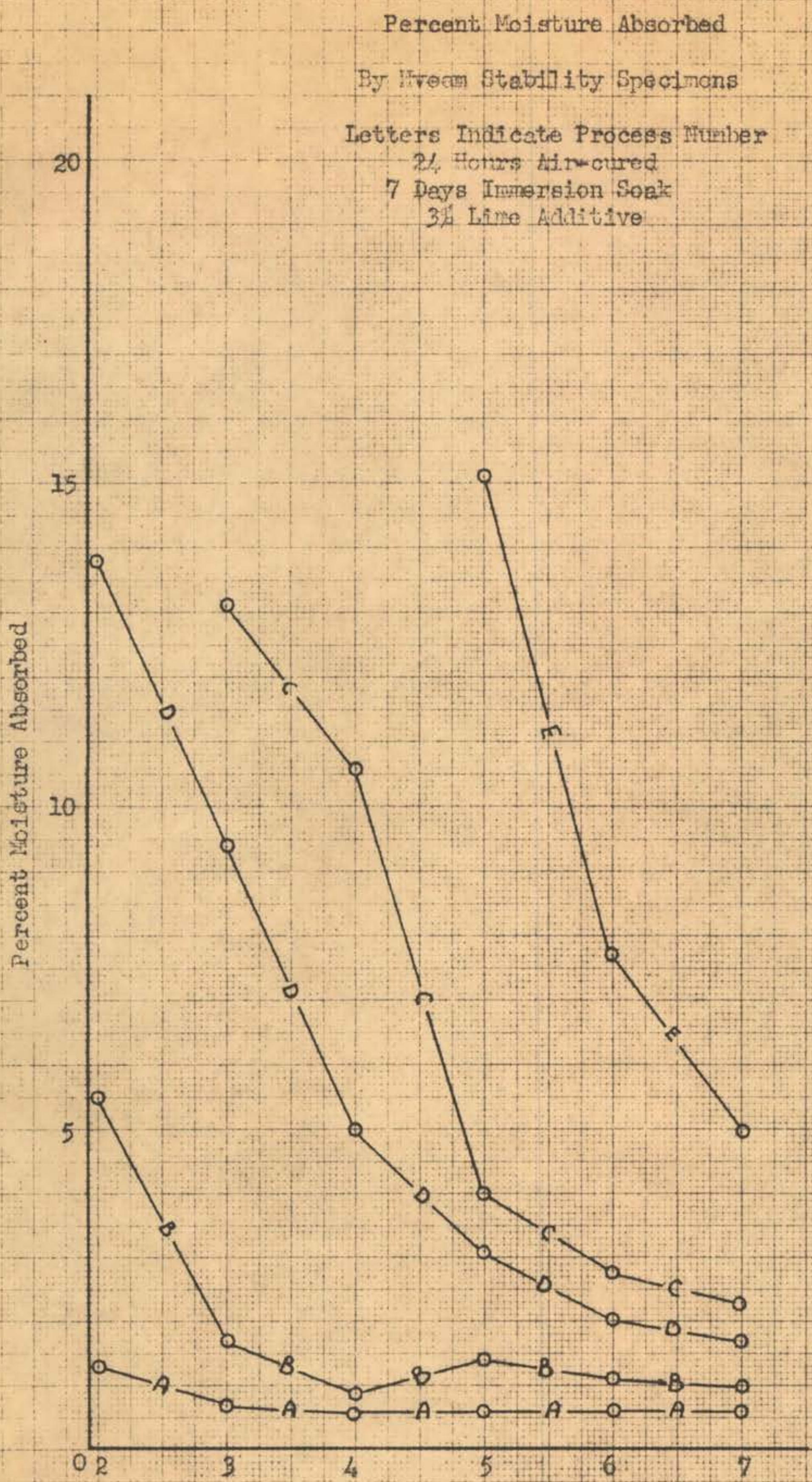


Fig. 11. Percent MC-3 Asphalt

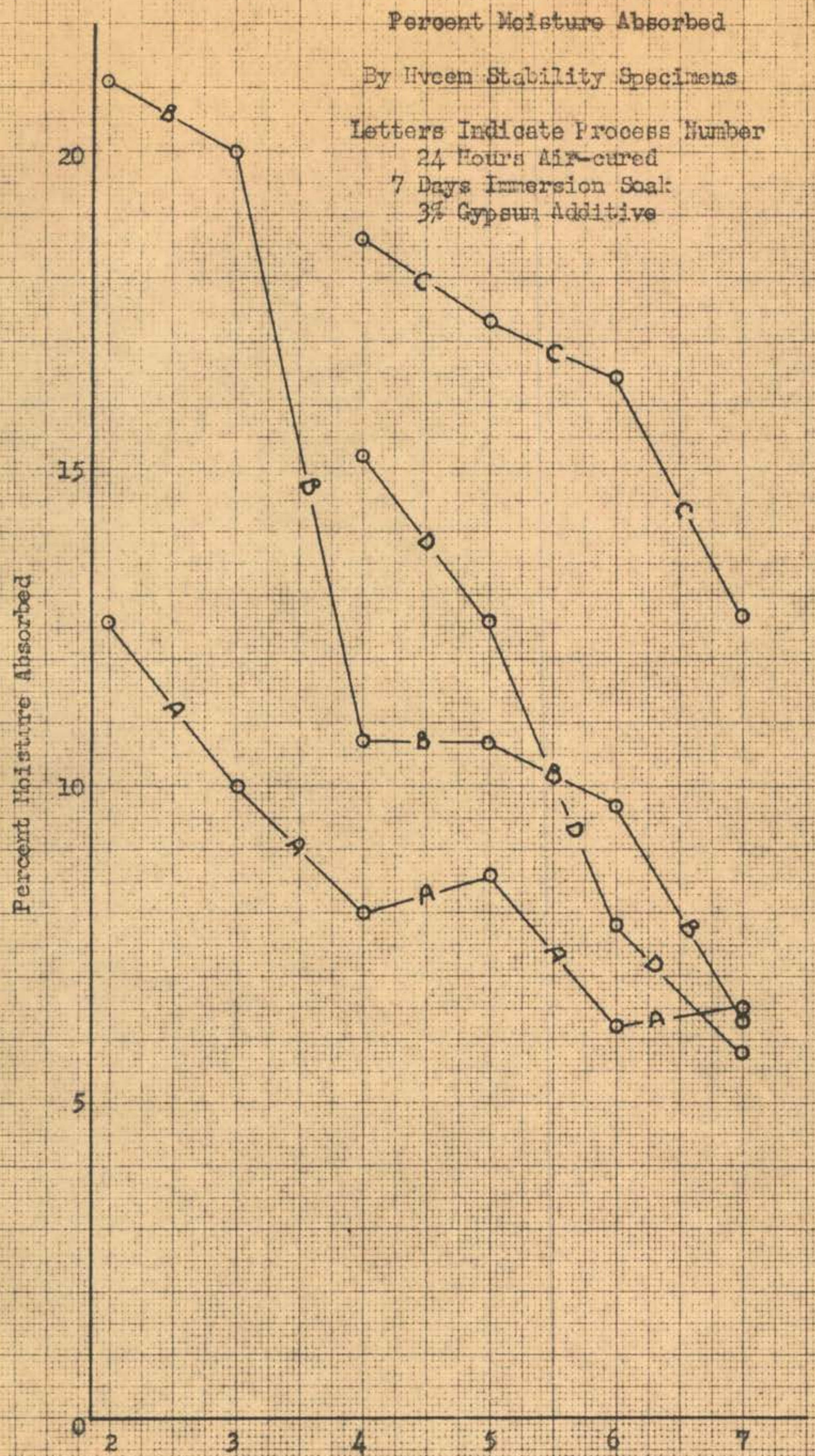


Fig. 12. Percent MC-3 Asphalt

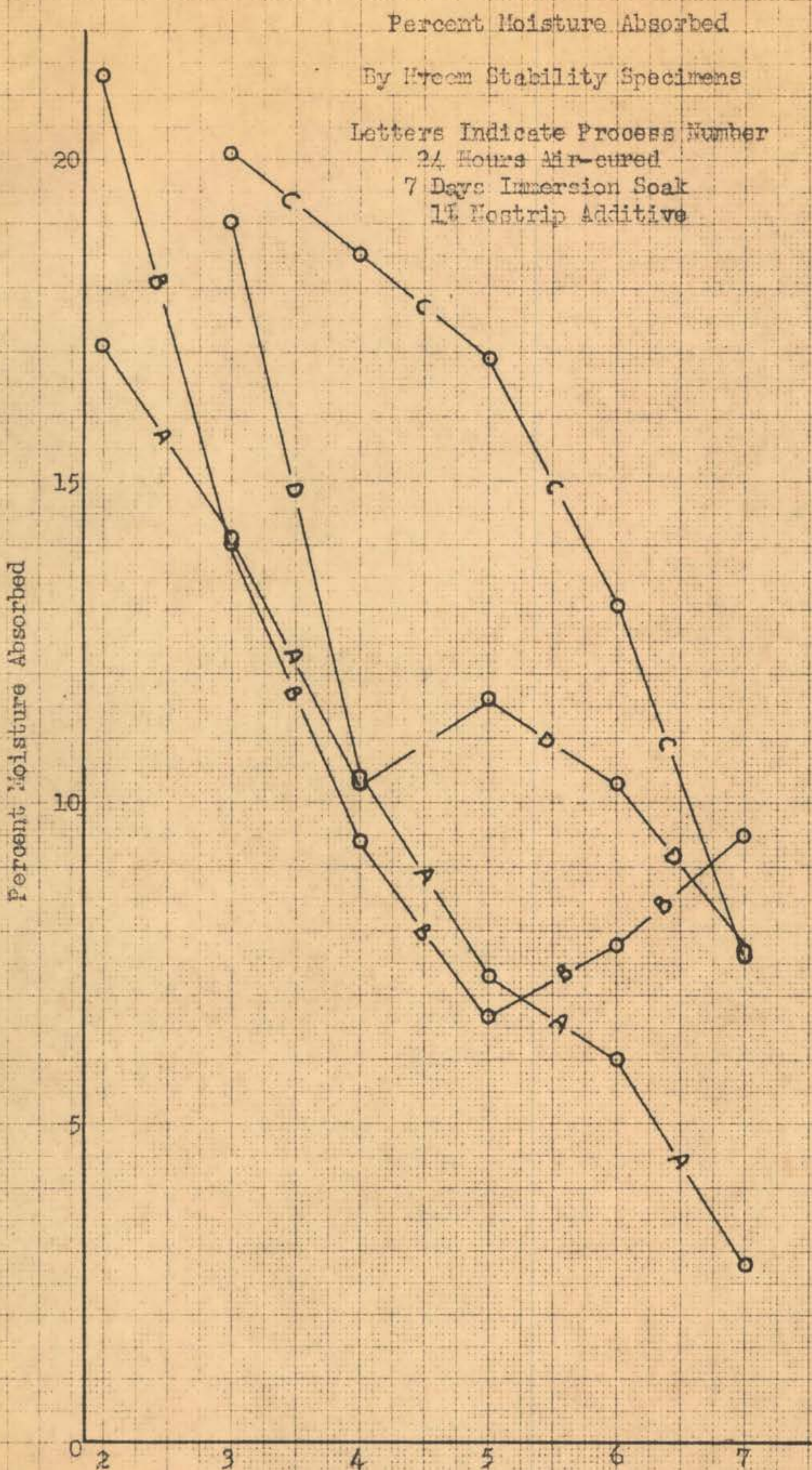


Fig. 13. Percent MC-3 Asphalt

Hveem Stability Comparison of Lime Additive
In a Soil Having a Plasticity Index of 11.6

First Number = Percent of Additive
L = Lime, G = Gypsum, NA = No Additive
Last Number:
1 = 24 Hours Air-cured
2 = 24 Hours Air-cured, 7 Days Capillary Soak
3 = 24 Hours Air-cured, 7 Days Immersion Soak

LIME

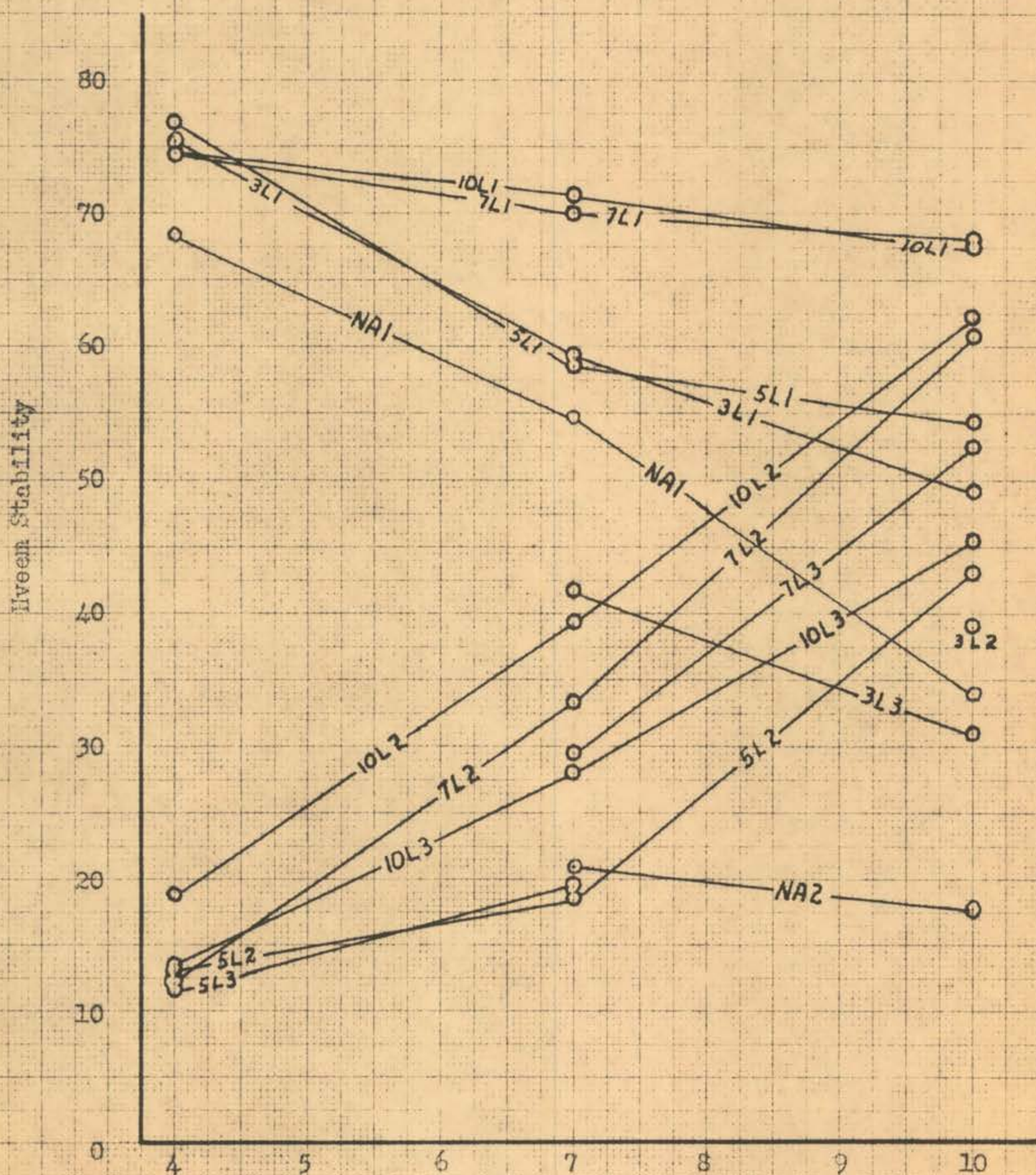


Fig. 14. Percent MC-3 Asphalt

Hveem Stability Comparison of Gypsum Additive
In a Soil Having a Plasticity Index of 11.6

First Number = Percent of Additive
L = Lime, G = Gypsum, NA = No Additive
Last Number:
1 = 24 Hours Air-cured
2 = 24 Hours Air-cured, 7 Days Capillary Soak
3 = 24 Hours Air-cured, 7 Days Immersion Soak

GYPSUM

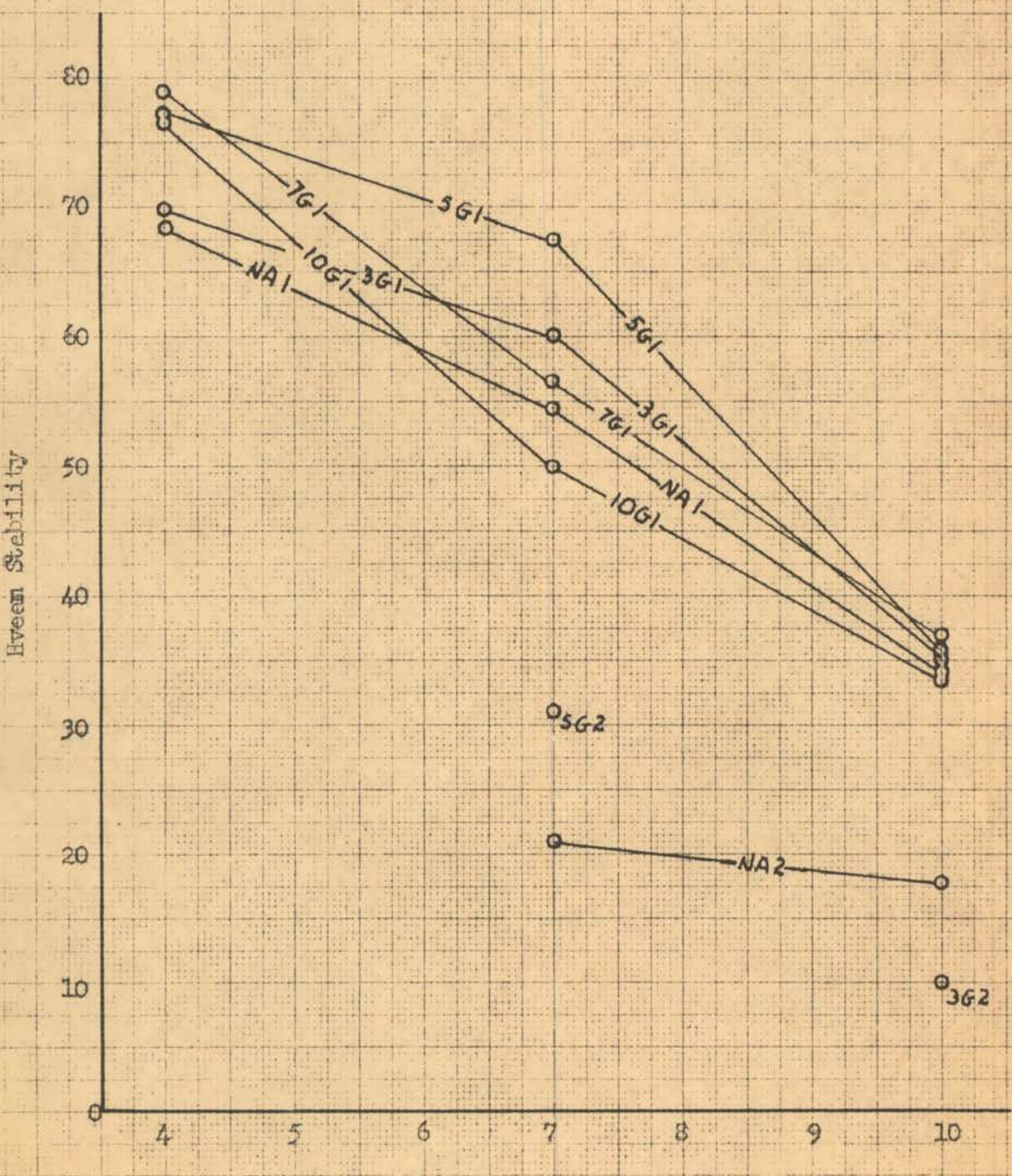


Fig. 15. Percent MC-3 Asphalt

Hveem Stability Comparison of Different
Percentages of Lime and Gypsum Additive
In a Soil Having a Plasticity Index of 11.6

First Number = Percent of Additive
L = Lime, G = Gypsum, NA = No Additive
Last Number:
1 = 24 Hours Air-cured
2 = 24 Hours Air-cured, 7 Days Capillary Soak
3 = 24 Hours Air-cured, 7 Days Immersion Soak

LIME - GYPSUM

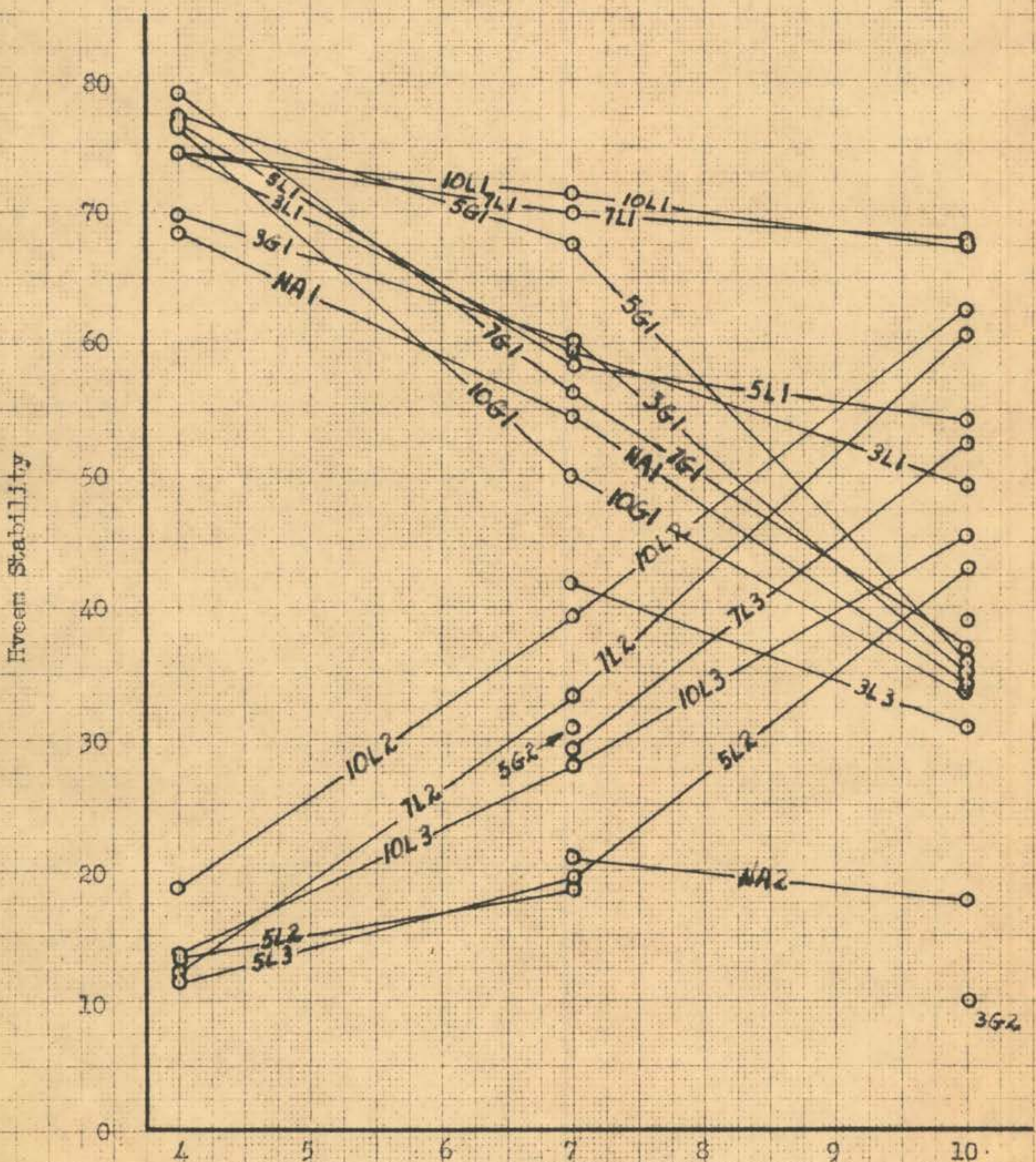


Fig. 16. Percent MC-3 Asphalt

Graph Analysis

Figure Number 2 through Figure Number 9 give a comparison of the six soils tested with different additives at varying percentages of medium-curing (MC-3) asphalt. In general, all additives, except Nostrip, increased the stability of the soil when it was tested after twenty-four (24) hours of air-curing. The decrease in stability is noticeable in all soils as the percentage of asphalt is increased. This decrease in stability indicates that the clay in the soil has given the greater part of the stability to the specimen at the lower percentages of asphalt, but the soil grains have become lubricated and unstable as the asphalt percentage is increased. This decrease in stability is more noticeable in the soils having the greater plasticity index.

A comparison of the specimens that have been air-cured for twenty-four (24) hours in relation to the companion specimens that have been immersion soaked for seven (7) days after the twenty-four (24) hours air-curing, will show that strength is a function of the plasticity index, percent of asphalt, the type of additive, and the water-proofing effect of the asphalt which involves all three of the other points mentioned.

All Hveem specimens were mixed and molded in the laboratory, as prescribed in Bulletin No. 69.[16] All dry additives were added to the dry soil as a percentage of the dry weight of the soil; Nostrip was added to the asphalt as a percentage of the total bituminuous material. Capillary soaking of Hveem specimens varied from immersion soaking in the respect that the capillary soaked specimens were placed in a pan on a one-half (½) inch thick, fine-grained, porous stone, and water was allowed to stand around the stone but not

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16 J. Rogers Martin, "Some Fundamental Principles in Relation to Asphaltic Concrete Pavements as Applied to the Hveem-Gyratory Method of Design," Oklahoma Engineering Experiment Station Publication, Oklahoma Agricultural and Mechanical College, Publication No. 69, (November,1948), 42-44.

allowed to touch the specimen, while the immersed specimen was set directly into the pan and the water level was maintained about 1/16 - 1/8 inch below the top edge of the specimen. In both cases, the pan and specimen were placed in a moist-proof cabinet that had water in the bottom of the cabinet.

In general, the stability of the soaked specimens is less than the stability of the specimens that have been air-cured. The stability increases as the percentage of asphalt increases since the additional asphalt provides some degree of water-proofing by more thoroughly coating the soil particles and filling some portion of the voids among the soil grains.

Figure Number 10 through Figure Number 13 shows the percentage of moisture absorbed by the different soils at varying asphalt percentages during the seven (7) days of soaking. Process "E" and "F" soils without additive did not withstand the period of soaking to an extent to allow stability determinations. The specimens that had 3% Hydrated Lime were consistently the ones that absorbed the least water.

Figure Number 14 through Figure Number 16 presents a comparison of the stabilities of a soil having a plasticity index of 11.6 when used with lime or gypsum, different percentages of medium-curing (MC-3) asphalt, and cured by three methods for a comparison of the soaking possibilities.

Since the soil-asphalt stabilized road bases in Oklahoma are built in the western part of the state where there is not a great amount of rain each year, and since there would hardly ever be a time in the history of such a road base when it would be submerged in water for a week's period, the capillary soaking was attempted in an effort to find a logical soaking period that would simulate the worst conditions found on the existing roads.

In general, the capillary method of soaking gave better stability values than the immersion soaking. The specimens having lime as an additive gave better results than the specimens with gypsum as an additive, for like percentages of additive.

# Chapter X

## Summary, Conclusions, and Recommendations

### Summary

Although soil and asphalt mixtures were used by pre-historic man, the successful stabilization of soil, with asphalt, is considered to be a relatively new science.

Much of the available information about soil-asphalt stabilization is inconclusive, incomplete, and uninformative. The general opinion of highway engineers has been that it was impossible to successfully stabilize any soil that had a plasticity index greater than ten. Opinions vary as to the best type and grade of asphalt that may be used for stabilization of soils; however, much of the diversity of opinion is due to differences in the soils found in the various parts of the country.

Six Oklahoma soils have been stabilized with a medium curing (MC-3) asphalt in percentages varying from two to 10 (2 - 10) percent asphalt, with and without additives, in order to study the soils, the additives, and the differences in additives as they apply to the various soils tested.

### Conclusions

Soils may be stabilized with asphalt, or asphaltic materials, without difficulty if the soil to be treated has a plasticity index less than ten. Soils that have a plasticity index greater than ten must be carefully analysed, tested, and experimented with in the laboratory before any conclusive facts can be known about the ability to stabilize them. Hydrated lime shows excellent results on materials having more than a zero plasticity index. Much more work needs to be done in the laboratory with both slaked and unslaked lime. The unslaked lime might very easily be the answer that engineers are seeking for the stabilization of soil with asphalt and additives, the answer cannot be fully determined until some catalyst is found that will start the reaction of the unslaked lime. At the present time gypsum powder does not seem to be worthwhile as an additive in soil-asphalt stabilization. Lump gypsum, or a different powdering of gypsum, might give better results.

Nostrip apparently neither helps nor hinders soil-asphalt stabilization. The non-benefit of Nostrip might be explained by the fact that it is supposed to help adhesive materials, such as asphalt, stick to wet aggregates, whereas the soil-asphalt mixtures must be moist in order to facillitate mixing. The size of the particles involved might also be a factor that has not been investigated.

The "Fluff-point" of the soil is the best place to add asphalt and liquid additives to the soil, since the "Fluff-point" is that point at which there is a maximum of voids in the soil.

When curing soil-asphalt mixtures in the field, the volatiles must be cured-out to some point in the range of one-third to one-fifth (1/3 - 1/5) of the original volatiles.

Recommendations

A study of existing soil-asphalt road-bases, and the laboratory analyses of the facts and theories of soil-asphalt stabilization has led to the recommendation that is shown in Table No. 11. Table No. 11 is an attempt to give a general idea of what must be expected in the way of a soil for soil-asphalt work. In the past, the specifications for this type of work have been far too brief (as shown by Table No. 1 on Page No. 5).

Table 11

| Suggested Soil Specifications for Soil-Asphalt Stabilization *** | | |
|---|---|---|
| Percent passing | 2.5" sieve | 100.0 |
| Percent passing | 1.0" sieve | 90 - 100 |
| Percent passing number | 4 sieve | 75 - 100 |
| Percent passing number | 10 sieve | 65 - 100 |
| Percent passing number | 40 sieve | 50 - 85 * |
| Percent passing number | 200 sieve | 20 - 50 |
| Liquid Limit of minus number 40 material | | less than 30 |
| Plasticity Index of minus number 40 material | | less than 10 ** |

* This gradation is difficult to obtain in Oklahoma, and should be 50 - 100 in most parts of Oklahoma.

** Best results will probably be achieved with a plasticity index from 1 to 5.

*** This Table of Suggested Specifications is not to be considered as "Iron-Bound". Judgment must be exercised by the engineer in charge, so as to allow for local soil conditions, road use, etc.

Since soil-asphalt stabilized road-bases were originally a low-cost method of using in-place materials for improvements on farm-to-market roads, the specifications had to be "wide-open" to permit in-place materials to be used in most cases.

If the material must be hauled-in, then the low-cost argument that favors soil-asphalt stabilized road-bases is of no value, and the construction of such road-bases will be slowed down.

In order that the cost may be maintained at its present low level, considerable laboratory research, for an additive with which to aid the stabilization of soils having a plasticity index greater than ten, is more than justified. Soil-asphalt stabilized road-bases are ready to be promoted from farm-to-market roads to first class highways in the State of Oklahoma, and since Oklahoma has done much toward being the leader in the field of soil-asphalt stabilization, other states will follow the trend once it has been started.

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NAME OF AUTHOR: JAMES C. JOHNSON

THESIS ADVISER: J. ROGERS MARTIN

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