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The Design and Control of Hot Plant Mix Pavement

Thomas Gordon Brown

BROWN

HOT
PLANT
MIX
PAVEMENT

THE DESIGN AND CONTROL OF HOT PLANT MIX PAVEMENT

By

Thomas Gordon Brown

A Thesis

Presented in Partial Fulfillment of the

Requirements for the Degree of

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Civil Engineering

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MASTER OF SCIENCE

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May 25, 1950

DATE

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Thesis committee

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CHAPTER I

INTRODUCTION

The objective of this thesis iis to find and recommend a practical and efficient Desiggnn and Control of Hot Plant Mix Bituminous Pavement.

For many years in New Mexico, bbituminous road construction has been done by the road mnix or traveling plant method. In the earlier development oof the highway system, this method worked out very well, beeccause of light traffic and low wheel loads. With the increasaase in wheel loads of trucks, up to 18,000 pounds axle loaadis, the light mixed in place pavements just couldn't takkce it.

There are several reasons for the failure of the cold mixed in place pavements. Drawing uppoon many years of actual experience in laying this type of pavveements on New Mexico highways, the author offers the follcowwing observations: 1. It is very difficult, and sometimmees impossible, to control the moisture in the wind-roweedd material. 2. The gradation of the material, as wind-roowwed on the road prior to mixing with the cut-back asphalt cceement or road oil, is varied. This variation naturally chaannges the amount of oil as computed by the Surface Area Methoodd. On practically all projects, the material for the oil maatt is produced and stockpiled prior to placing on the road. EEven with careful

inspection and manipulation, there is always a large amount of segregation of the larger and finerr sizes of the material. The result is that four or five hundreed feet of the wind-row will be composed of coarse materiaal and the next four or five hundred will be all fines. Thhe material may be processed back and forth across the road,, but if the gradation is not correct to begin with, no amounnt of processing with a blade will correct this discrepancy.. 3. One of the most important steps in the building of anyy mixed in place bituminous pavement is the mixing of the CUut-back bituminous material or Road Oil with the aggregatte. The aggregate and bituminous material are mixed eithher by processing back and forth across the road with a blade grader or by a traveling plant which picks up the wwind-rowed material and passes it through a pug-mill, depoositing the mixed material in a wind-row at the rear of the traveling mixer. The mixed material still has to be mixed by blades to aerate the material.

In the blade mix method, the maaterial in the wind row is bladed or flattened across the roadway to the correct (or as near as possible) depth annd then the bituminous material is applied in the specified ammount by the use of a distributor (usually 1200 gallons cappacity). It can readily be seen that this method of appplying the Cut-back or Road Oil is a haphazard operation. The accuracy depends

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upon the calibration of the distributor as to nozzle capacity and the speed of the distributor on the road.

In the traveling plant method, the application of the bituminous material to the aggregate in the pug-mill is obtained by the use of a spray bar in the pug-mill and a metering device. This method is more accurate than the distributor method, but if the amount of bituminous material required is not correct, due to poor gradation in the wind-row, no amount of metering of the bituminous material will help the mix.

The last step, which has caused more trouble than any other phase of the work, is the time of mix or the number of times the mixed wind-row shall be processed to properly aerate the mix so as to get rid of the volatile material in the cut-back asphalt. This is more important in the MC (Medium Cure) than in the RC (Rapid Cure) cut-backs. The SC (Slow Cure) road oil is a product of distillation and does not have a cut-back added. (MC is cut back with kerosene; RC is cut back with naptha or high test gasoline.) It can readily be seen that if the volatile material stays in the mat and the mat is laid down, rolled and sealed with an asphalt cement 200—300 penetration and chips, an unstable mat will result. This is due to the lubrication effect of the cut-back in the MC or RC, or the small amount of fuel oil that is in the SC.

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The advantages of the "Hot Plant Mix" are summarized as follows: 1. Exact control of the moisture content and temperature of aggregates is maintained by the use of a Mechanical Drier. 2. The gradation of the coarse and fine aggregates is controlled. The aggregates are rescreened after passing through the drier; the different sizes of aggregates are screened into three different bins. The aggregates are recombined either by weight or volumetric control, depending upon which type of plant is used. In a batch plant, all measurements including asphalt cement are by weight. In a continuous mix plant measurements are by volume. (Calibrated gates or orifices.) By either of the above mentioned methods the exact amount of the properly graded aggregates is introduced into a twin-shaft pug-mill. 3. The mixing is accomplished in a pug-mill, which consists of a long steel covered trough, containing a double shaft that is equipped with blades set at proper angles to insure a homogenious mix. The asphalt cement is introduced into the pug-mill by the use of a spray bar. The proper amount of asphalt cement is either weighed or metered into the pug-mill, at the end of the dry mixing period. The asphalt cement and aggregate are mixed at the specified temperature for the proper length of time as determined by the job mix formula. 4. The mixed material is conveyed in trucks (so equipped to maintain the proper temperature)

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to the job. The delivered material is dumped from the trucks into a hopper of the Lay Down Machine and evenly distributed onto the prepared base, after which it is rolled (compacted) to the proper density by rollers.

The above comparison of the methods used in the Mixed in Place Method and the Hot Plant Mix Method are made for the purpose of proving that the out-dated Mixed in Place Method is obsolete, because there is no known method by which accurate control of the various constituents can be accomplished. (When using the Mixed in Place Method.) On the other hand, the Hot Mix Plant Method affords every facility for accurately controlling all materials and operations.

There are now at least six companies that manufacture up to date Hot Mix Plants of approved design. It has been proven in other states that if a Hot Plant Mix is designed properly, the mix can be produced according to the design by any approved plant that is operated according to specifications based on the design of the mix.

This thesis is based on a design for a Hot Plant Mix pavement used in the construction of the Federal Aid Urban Project in Tucumcari, New Mexico. The author worked on this design as Research Graduate Course (C.E. 213L) in the spring semester, 1949. The material in this thesis covers two designs, using different gradations of aggregates.

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The Hveem and Marshall Methods were both used. The final design was based on using the Marshall Method.

The project was completed in August, 1949, and the author has been able to make several inspections of the finished pavement, and also to make several checks of the additional density obtained due to traffic. Up to the present time there have been no visible failures in this pavement.

The control of the mix at the plant was accomplished by using a Marshall Apparatus to make frequent stability and flow tests. Extraction and density tests were made at frequent intervals. There was very little variation in the mixed material.

Due to the high cost of this type of pavement, it is very important that the best design be obtained prior to writing the specifications and establishing the job formula, and also strict control of the mix be made at the plant. It is essential that rigid inspection be maintained at all times on this type of bituminous pavement.

CHAPTER II

STUDY OF EXISTING TEST METHODS

Existing information and testt data on the more common methods of asphalt pavement desiign and control were studied to determine the relative meerits of the various methods.

At the University of New Mexiico there are three different types of apparatus available for conducting tests which are essential to asphalt pavemment design.

The several methods using thee different apparatus, with brief descriptions, are listed in the following order:

1. Hubbard-Field Method.

The Hubbard-Field Stability TTest is an extrusion type of test in which a 6-inch diameter bby 2-inch thick specimen is forced through a testing ring 5-33/4 inches in diameter by means of an axial load applied att a rate to produce deformation of one inch in 25 seconds.. The Hubbard-Field stability is the total maximum load applied to create failure of the specimen.

The Hubbard-Field method comppares fairly well with other methods, with the following exxceptions:

(a) Determination of optimumm bitumen quantity. This test fails to be diistinct in approximately one-half of the cases.

STUDY OF EXISTING METHODS

Existing information [illegible] com-
mon methods of asphalt [illegible]
studied to determine the [illegible] of the various
methods.

At the University [illegible] there are [illegible] dif-
ferent types of [illegible]
which are [illegible]

The several [illegible]
with brief descriptions [illegible]

1. Hubbard-Field Test.

The Hubbard-Field [illegible]
of test in which [illegible]
is forced through [illegible]
by means of an [illegible]
formation of one [illegible]
stability is the [illegible]
failure of the specimen.

The Hubbard-Field [illegible]
other methods, with [illegible]

(a) Determination [illegible]

This test [illegible]
one-half [illegible]

(b) High sensitivity to temperature.

(c) The Hubbard-Field testing apparatus is large and bulky and is not easily portable.

(d) The design features of the machine are not adaptable to California Bearing Ratio Test equipment.

2. <u>Hveem Stabilometer Method</u>

The Hveem stabilometer test is very good to determine the optimum bitumen content, but it is not very sensitive to graduation and aggregate type and changes.

This test does not lend itself to routine investigations because it does not take into account the cohesion. Mr. Hveem is now using a cohesiometer in connection with the stabilometer, which should give good results. The cohesiometer was not available for the test covered in this investigation.

3. <u>Marshall Stability Method</u>

This method of test and apparatus was designed by Bruce G. Marshall, formerly connected with the Materials Division of the Mississippi State Highway Department. The apparatus has been used by the Army Corps of Engineers in the design of pavements for air-fields. Very satisfactory results have been obtained using this method.

The Marshall test is a semi-confined, compression-type shear test in which a 4-inch diameter by 2 1/2-inch

thick specimen is compressed between two segments of a 4-inch diameter (inside) ring. Shear planes developed within the specimen divide it into four pieces at the time of failure.

The stability value is the maximum total load in pounds required to produce failure.

The flow value, as determined by the Marshall test, is a relative measure of the amount of movement the specimen has undergone at the point of failure. It is a measure of the flexibility of the test specimen.

Summary of Existing Methods

Careful study of the three different methods, namely Hubbard-Field, Hveem, and Marshall, revealed that the Marshall method was better adapted to general investigation work in connection with asphalt design than the Hubbard-Field or Hveem methods, for the following reasons:

(a) The Marshall method has given apparently satisfactory results in the years it has been used, especially near the end of the late war.

(b) The Marshall testing apparatus is easily portable and can therefore be used in the field to check Hot Mix specimens at the plant.

(c) The Marshall equipment can be adapted to existing California Bearing Ratio equipment.

(d) The stability test is believed to be equally as

thick specimen in [illegible]

4-inch diameter (inside) [illegible]

in the specimen [illegible]

failure.

The stability [illegible] load in

pounds required to [illegible]

The flow value [illegible]

is a relative measure [illegible]

men has undergone [illegible]

of the flexibility of [illegible]

<u>Summary of [illegible]</u>

Careful study of [illegible]

Hubbard-Field, Hveem, and [illegible]

Marshall method [illegible]

work in connection with [illegible]

Field or Hveem methods, for the [illegible]

(a) The Marshall [illegible]

factory results in the [illegible]

near the end of the [illegible]

(b) The Marshall [illegible]

and can therefore be [illegible]

specimens at the [illegible]

(c) The [illegible]

ing California Bearing [illegible]

(d) The stability [illegible]

good as the Hubbard-Field.

(e) The determination of optimum bitumen quantity is far superior to either the Hubbard-Field or the Haveem methods.

CHAPTER III

SELECTION OF DESIGN AND CONTROL METHODS

On the basis of preliminary laboratory investigations of the three available methods of test (Hubbard-Field, Hveem, and Marshall), it was decided to use both the Marshall and Hveem methods.

By using two different methods on the same specimens of a mix, the good qualities of the two methods could be brought out and also a check would be made against each method.

The two types of equipment that were selected for the investigation are described as follows:

Marshall Stability Apparatus

The equipment consists of compaction molds, compaction hammer, and the Marshall stability apparatus, consisting of a breaking head and flow meter. A suitable compression testing machine is required to perform the stability test. Other appurtenant equipment as hereinafter listed is required for controlled production of the test mixtures. Brief descriptions of the equipment are given in the following paragraphs.

Compaction Mold. The compaction mold consists of a base plate, mold cylinder, and collar. The mold cylinder is four inches inside diameter with its inner surface machined

smooth, and approximately 3 1/2 inches in height. The mold is so constructed that the base plate and collar may be fitted to either end. The collar has an inside diameter slightly larger than four inches. At least two compaction molds are required, and four are desirable.

Compaction Hammer. The compaction hammer consists of a ten pound weight falling through a distance of eighteen inches and striking a flat circular foot with a diameter of 3 7/8 inches. The hammer is guided in its fall by sliding along a vertical rod. Two compaction hammers are desirable so that one may be heating while the other is in use, thus permitting continuous operation.

Marshall Breaking Head. The breaking head consists of an upper and lower test head with inside radii of curvature of two inches. The inside face is machined smooth. The lower test head is mounted on a base having two perpendicular guide rods extending upward. Guide sleeves in the upper test head are positioned so as to direct the movement of the two test heads together without binding or loose motion. When 4-inch diameter specimen is in testing position, the terminals of the two heads are separated by a distance of 3/4 inch on each side. In this position the guide rods protrude slightly above the top of the upper test head.

Marshall Flow Meter. The flow meter consists of a

smooth, and approximately 3 1/2 inches in height. The mold is so constructed that the base plate and collar may be fitted to either end. The collar has an inside diameter slightly larger than four inches. At least two compaction molds are required, and four are desirable.

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Marshall Flow Meter. The flow meter consists of a

gauge sliding with slight friction inside a body which in turn slides freely over either guide rod of the breaking head. The divisions on the gauge are made on the inside rod and are numbered every 1/32 of an inch. (Can be obtained with graduations in hundredths of an inch). The height of the flow gauge is approximately one inch.

Compression and Testing Machine. The compression and testing machine may be any suitable device which will apply vertical pressure to the breaking head by means of a movable plate which operates at a speed of two inches vertical rise per minute. The testing machine must be equipped with a load-measuring device having a capacity of 5000 pounds and sensitive to a ten pound load up to 1000 pounds and a 25 pound load up to 5000 pounds.

The apparatus used in this work consisted of a standard Marshall apparatus which was equipped with an electric motor and suitable gears to operate the machine at the proper speed.

Appurtenant Equipment.

1. Heating units of adequate capacity for heating aggregates, asphalt cement, and water.

2. Armored theromemters with a maximum sensitivity of five degrees Farenheit, with a range between 50 degrees Farenheit and 400 degrees Farenheit.

3. Theromemters with one degree Farenheit range

capable of measuring temperatures to 140 degrees Farenheit.

4. Hot water bath with perforated, false, flat bottom for heating aggregates and test specimens.

5. Mixing trowel or ice-cream spoon.

6. Pans for heating aggregates and asphalt cement.

7. A compaction base, either a built-in 12 by 12 post or similar construction, so that it is level and free from vibration or rebound.

8. A five kilogram balance sensitive to one gram with appropriate weights.

9. A one kilogram balance sensitive to 0.5 gram.

Hveem Stabilometer Apparatus

The equipment consists of compaction molds, compaction hammer, and the Hveem stabilometer. A suitable compression testing machine is required to deliver the axial load to the Hveem stabilometer. Brief descriptions of the necessary equipment are given in the following paragraphs:

Compaction Mold. The compaction mold was the same that was used in the Marshall test. The fact that the specimen size for the Marshall and Hveem apparatus are the same came in very handy, due to the fact that the original molds that belonged to the Hveem apparatus had been lost or misplaced at the time this test was being made. The molds are described under "compaction molds" Marshall Stability Apparatus.

Compaction Hammer. The same compaction hammer was used in the preparation of the specimens for both the Marshall and Hveem tests. This hammer is described in detail under the Marshall appartus description.

Hveem Stabilometer. The Hveem stabilometer is an instrument for subjecting the 2 1/2 inch by 4 inch diameter specimen to tri-axial compression. This apparatus measures the transmitted horizontal pressure resulting from an applied vertical pressure. The apparatus is shown by diagrammatic sketch on page 17. The apparatus consists of the following major parts:

1. Piston for applying load to specimen. (From the head of the testing machine.)
2. Metal case, containing a flexible rubber diaphram. There is a cell or space between the outer metal shell and the rubber diaphram, which contains a liquid under a small initial pressure.
3. An adjusted stage or base on which the specimen rests. This base rests on the platen of the testing machine.
4. A pressure gauge recordimg pounds per square inch.

Compression Testing Machine. Compression testing machine, minimum capacity of 20,000 pounds, capable of being regulated so as to apply the test load at a head speed of

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4. A pressure gauge recording pounds per square inch.

<u>Compression Testing Machine</u>. Compression testing machine, minimum capacity of 20,000 pounds, capable of being regulated so as to apply the test load at a head speed of

0.05 inch per minute.

Appurtenant Equipment. The same appurtenant equipment was used as is listed in the Marshall test apparatus.

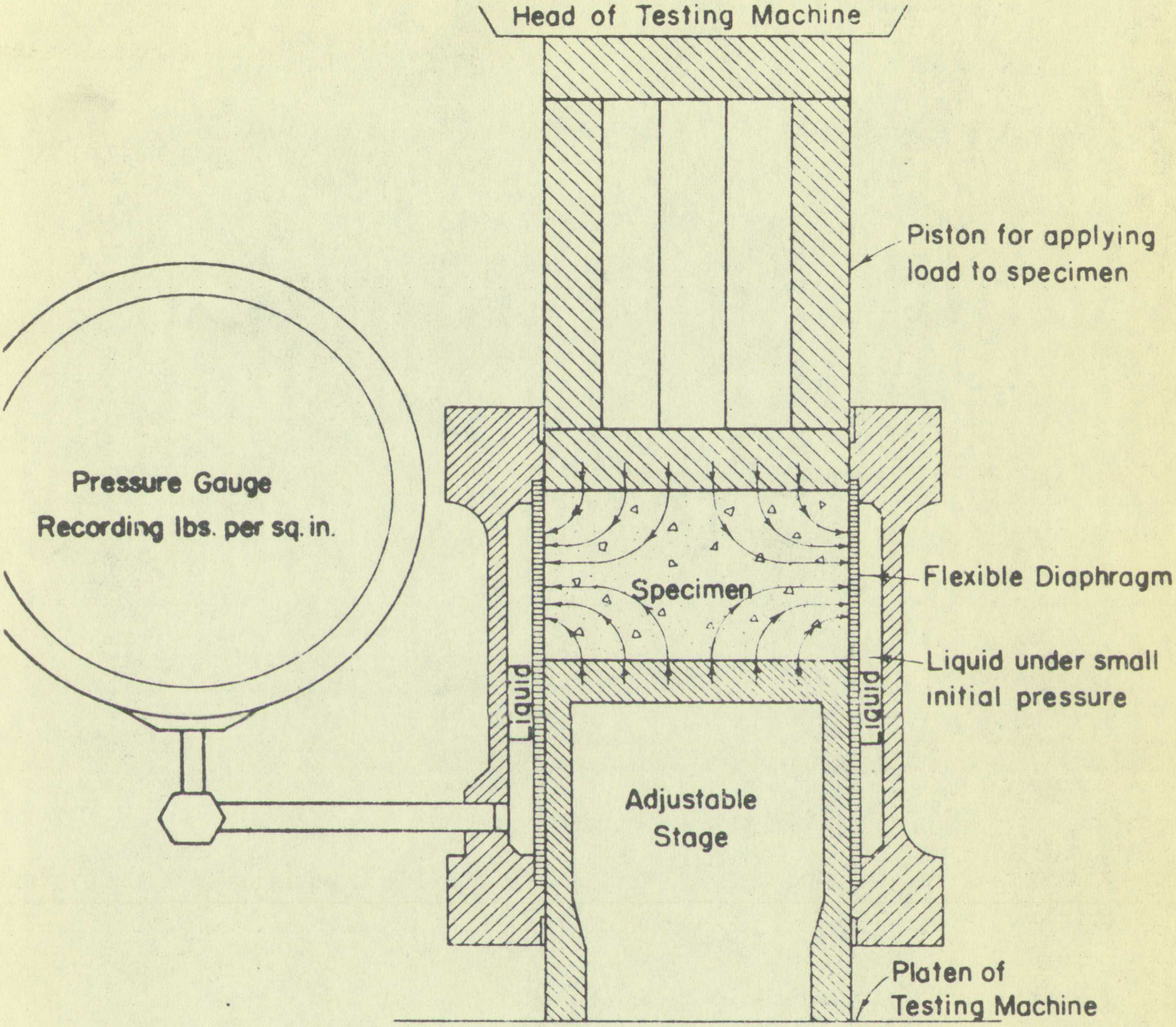
0.05 inch per minute.

[illegible]. [illegible]

ment was used as [illegible]

CHART 1

DIAGRAMMATIC SKETCH of the HVEEM STABILOMETER



Note:

Specimen given lateral support by flexible side wall which transmits horizontal pressure to liquid. Magnitude of pressure may be read on gauge.

[redacted]

CHAPTER IV

PRESENTATION AND ANALYSIS OF LABORATORY TEST DATA

After selection of the test apparatus, a laboratory test program was set up to determine the test properties of the specimens and to set up a design criteria.

The test properties and definitions relating to same are listed as follows:

Stability. The ability of the pavement to resist the shearing stresses imposed by the wheel loads without displacement.

Marshall Stability Value. The maximum load in pounds required to produce shear failure in a compacted specimen of asphalt paving mixture when tested in the Marshall apparatus.

Hveem Stability Value. The Hveem stability is a relative stability value. The resistance value of the material is directly proportional to the maximum shearing stress divided by the major principal stress.

R_1 = Resistance value of material tested

P_v = The applied vertical pressure (typically 160 P.S.I.)

P_h = The transmitted horizontal pressure (stabilometer reading)

$$R_1 = (1 - \frac{P_h}{P_v}) 100$$

CHAPTER [illegible]

PRESENTATION [illegible] OF [illegible]

[illegible]

After selection of the test [illegible] test program was [illegible] the specimens and [illegible]

The test [illegible] are listed as follows:

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Marshall Stability Value. The [illegible] required to produce shear failure in [illegible] of asphalt paving mixture [illegible] in the Marshall [illegible] ratus.

Hveem Stability Value. The Hveem stability [illegible] relative stability [illegible] the resistance [illegible] material is directly proportional to the [illegible] stress divided by the major (vertical) stress.

R_1 = Resistance value [illegible]

P_v = The applied vertical pressure [illegible]

P_h = The transmitted horizontal pressure [illegible] reading)

$R_1 = (1 - \frac{P_h}{P_v})\ 100$

S = Relative stability value in per cent

$$S = \frac{22.2}{\left(\frac{RD}{400-R}\right) + 0.222}$$

R = Stabilometer reading at 400 P.S.I. applied load.

D = Turns displacement on specimen.

Flow Value. The total deformation, measured in 1/32 of an inch, that occurs in the compacted specimen of the paving mixture at the point of maximum load subjected to the Marshall stability test.

Unit Weight Total Mix. The total weight of an asphaltic mixture, including all aggregates and asphalt, in pounds per cubic foot.

Unit Weight of Aggregate Only. The total weight of all aggregates in an asphaltic mixture in pounds per cubic foot.

Per Cent Voids Aggregate Only. The total percentage of voids in the compacted aggregate mass including those occupied by asphalt and air. The term is synonymous with aggregate voids and per cent voids in the mineral aggregate and is the complement of per cent solids aggregate only.

Per Cent Voids Total Mix. That part of the compacted asphalt mixture not occupied by aggregates or asphalt expressed in per cent of the total volume. It is synonymous with air voids and is the complement of per cent solids in the total mix and per cent of theoretical maximum density.

Theoretical Maximum Density. The theoretical specific gravity of the total asphalt mixture in which it is assumed that all voids are eliminated. If expressed in pounds, the value is multiplied by 62.4.

Per Cent Voids Filled with Asphalt. The percentage of the voids in the compacted aggregate mass which are filled with asphalt cement. It is synonymous with asphalt void ratio.

Optimum Asphalt. That asphalt content in a pavement mixture which is judged to be most desirable by one or more criteria.

As set forth in Chapter I (Introduction) the basis for this investigation was the design of a Dense Graded Hot Plant Mix surface course for a municipal paving project in Tucumcari, New Mexico.

The following materials were set up to be used in the design:

1. Aggregates

The coarse and fine aggregates consisted of pit run gravel obtained from an average of ten test holes. The pit from which these samples were lifted is located near Tucumcari, New Mexico. The two hundred pound sample was run through the small jaw crusher in the laboratory. From the crusher run material, two samples were taken. These samples were designated as I-A and I-B. The grading for sample I-A was tentatively set as follows:

(A.A.S.H.O. -- T-27)

Sieve Designation	Percent Passing by Weight
3/4"	100%
#4	40-60
#10	25-45
#40	15-30
#200	5-10

Sample I-B

1"	100%
3/4"	75-100
#4	40-60
#10	25-45
#40	15-30
#200	5-10

A composite sample of approximately 60 pounds was made up for design I-A and design I-B, using the median of the above gradings.

From field explorations and sieve analysis of the pit run and also of the crusher run material, it was believed that an aggregate conforming to either of the above gradings could be produced without wasting or importing any material.

2. Bituminous Material

The selected grade of asphalt was 120-150 penetration asphalt cement.

3. Asphalt Content

The asphalt content to be used in both designs I-A

and I-B was varied in 0.5% increments as follows:

4.0%

4.5%

5.0%

5.5%

CHAPTER V

PREPARATION OF SPECIMENS

1. General requirements as to size, weight and volume. The approximate amount of material (coarse and fine aggregate) required to make one specimen four inches in diameter and two and one-half inches high (compacted) was arrived at by using the following simple relation:

Volume of four-inch diameter specimen in mililiters equals height in inches multiplied by 205.9264.

Weight in grams of the material will be the volume in mililiters multiplied by the specific gravity of the material.

Example: Specimen four-inch diameter two and one-half inches high.

Volume = 2.5 x 205.9264 = 514.8160 ML

Specific gravity of mix after asphalt is added was approximately 2.3 514.8160 x 2.3 = 1184.076 grams

Asphalt approximately 5% by weight = 60 grams

1184 - 60 = 1124 grams

Use approximately 1100 grams of combined coarse and fine aggregates.

2. Grading of aggregates. To obtain a composite sample of the material, so as to obtain the grading required, the sample of crusher run material was divided on the following sieves: 1", 3/4", #4, #10, #40, and #200. The

CHAPTER V

PREPARATION OF SPECIMENS

1. General requirements as to size, weight and volume. The approximate amount of material (coarse and fine aggregate) required to make one specimen four inches in diameter and two and one-half inches high (compacted) was arrived at by using the following simple relation:

Volume of four-inch diameter specimen in milliliters equals height in inches multiplied by 205.9264.

Weight in grams of the material will be the volume in milliliters multiplied by the specific gravity of the material.

Example: Specimen four-inch diameter two and one-half inches high.

Volume = 2.5 x 205.9264 = 514.8160 ML

Specific gravity of mix after asphalt is added was approximately 2.3   514.8160 x 2.3 = 1184.076 grams

Asphalt approximately 5% by weight = 60 grams

1184 - 60 = 1124 grams

Use approximately 1100 grams of combined coarse and fine aggregates.

2. Grading of aggregates. To obtain a composite sample of the material, so as to obtain the grading required, the sample of crusher run material was divided on the following sieves: 1", 3/4", #4, #10, #40, and #200. The

material retained on each of the above sieves was placed in separate pans.

Example: Grading for specimen I-B

Sieve #	Per cent passing by weight
1"	100
3/4"	75-100
#4	40-60
#10	25-45
#40	15-30
#200	5-10

Median of the above grading was used. (See grading chart). Total sample (coarse and fine aggregate) for each specimen was taken as 1090 grams.

3/4" = 1090 x 12.5 = 136.25 grams

#4 = 1090 x 37.5 = 408.75 grams

#10 = 1090 x 15.0 = 163.5 grams

#40 = 1090 x 12.5 = 136.25 grams

#200 = 1090 x 15.0 = 163.50 grams

Passing #200 = 1090 x 7.5 = 81.75 (Included wash thru #200)

Totals 100% = 1090

3. Bituminous material. The bituminous material used in Design I-A and I-B was 120-150 penetration asphaltic cement.

4. Asphaltic content. The amount of 120-150 asphalt used in Design I-A and I-B was 4.0%, 4.5%, 5.0% and 5.5% by weight.

5. Laboratory Procedure. A sieve analysis and wash test was made on representative samples of each of the aggregates to be used, including the minus #200 (filler). The sieve analysis being known, the proper proportions of each material to be combined to produce the desired gradation was made. The correct percentages of each size and type of aggregate, mineral filler and asphalt cement were converted to the required proportions by weight to produce a specimen, when compacted, four inches in diameter and two and one-half inches in height. This amounted to approximately 1150 grams of total mix. In the two designs covered by this report, each design consisted of eight specimens. Four different asphalt contents were used. The asphalt contents were varied in 0.5% increments.

All separated fractions of coarse aggregate, fine aggregate, and mineral filler were heated separetely to temperatures between 350 degrees Farenheit and 375 degrees Farenheit. The asphalt cement was heated until its temperature was between 250 and 280 degrees Farenheit. In no case was the asphalt held at this temperature for more than one hour.

After all materials had attained the desired temperature, the mixing bowl was placed on the balance and tared. The aggregate and mineral filler were then placed in the bowl in their calculated proportions. The aggregates

were thoroughly mixed in the bowl with the trowel, and the temperature checked. The temperature should be between 300 and 350 degrees Farenheit. The bowl and aggregates were rebalanced on the scales and the correct amount of hot asphalt added.

Mixing was done as soon as the asphalt was added and was completed within two minutes. While mixing, the temperature was not allowed to fall below 225 degrees Farenheit.

Production of test specimens was initiated immediately after mixing was completed. The compaction hammers and compaction molds were heated to 250 degrees Farenheit, cleaned and made ready for use. All the mixture was first transferred from the mixing bowl to a large pan (it could be transferred directly into the mold from the mixing bowl.) The mixture was placed in three lifts and spaded around the sides with a spatula. It is very important that the temperature of the mix should not fall below 225 degrees during the molding and compaction process. After the mix was placed in the mold, the collar was removed and the surface of the mix smoothed with a trowel to a slightly rounded surface. The collar was then replaced and the surface of the mix leveled by using hand pressure on a heated sample extractor. The mold assembly was placed on a compaction base, the heated compaction hammer was placed on the specimen, and 55 blows of the hammer applied. After this the base

plate and collar were removed and the mold reversed and reassembled so that the base plate was adjacent to the original top of the specimen. Fifty-five blows of the compaction hammer were then applied to this face of the specimen. The specimen was then removed from the mold by use of the sample extractor. The specimen was properly identified as to mix and per cent of asphalt cement. Two specimens were made for each increment of asphalt cement. The height of the specimen should be 2 1/2 inches plus or minus 1/8 inch.

plate and collar were removed and the mold, reversed and re-assembled so that the base plate was adjacent to the original top of the specimen. <u>Fifty-five</u> blows of the compaction hammer were then applied to this face of the specimen. The specimen was then removed from the mold by use of the sample extractor. The specimen was properly identified as to number and per cent of asphalt cement. Two specimens were made for each increment of asphalt cement. The height of the specimen should be 2 1/2 inches plus or minus 1/8 inch.

CHAPTER VI

TESTING PROCEDURE

1. Bulk Volume. After removing the specimens from the molds, and properly identifying each speciman as to design number, percentage of asphalt, the specimens were allowed to cool to room temperature for twenty-four hours so as to avoid breaking the specimen.

At the end of twenty-four hours the specimens are carefully weighed in air and also while suspended in water. The weight in air minus the weight in water is the bulk volume of the specimen. The water should not contain an excess of suspended or dissolved materials and its temperature should be approximately 77 degrees Farenheit.

2. Marshall Stability and Flow Test. The specimen is immersed in a water bath at 140 degrees Farenheit for not more than an hour nor less than twenty minutes. The specimen is removed from the bath and fitted to the correct testing position on its side in the lower testing head of the breaking head of the Marshall apparatus. The complete assembly is then placed in testing position in the compression machine. The flow meter is placed on one of the guide rods and pressed down against the upper test head; the initial reading of the flow meter is taken and recorded. Pressure is applied by use of the electric motor, so that

the jack head rises at the rate of two inches per minute. Failure of the specimen occurs and is recorded when the load-measuring dial reaches its maximum reading and begins to recede back toward zero. The total number of pounds required to produce failure of the specimen is recorded as its stability. (See calibration table for proving ring #25, used in this experiment.)

In order to prevent excessive cooling of the specimen, with a resulting increase in stability, the entire test procedure is made in thirty to forty-five seconds from the time the specimen is taken from the hot water bath.

The flow value is obtained during the test for stability. During the time the load is being applied, the body of the flow meter is held firmly against the top of the upper test head so that the guide rod pushes the flow meter gauge upwards as the specimen deforms. When the maximum stability reading is obtained on the strain gauge, hand pressure on the guide sleeve of the flow meter is reduced instantly. After the stability reading has been recorded, the flow meter is removed from the breaking head and the final reading made. The difference between the initial and final readings expressed in 1/32 of an inch is recorded as the flow value.

3. Hveem Stability Test. At the start of each day's work the speed of the compression machine is checked

the jack head rises at the rate of two inches per minute. Failure of the specimen occurs and is recorded when the load-measuring dial reaches its maximum reading and begins to recede back toward zero. The total number of pounds required to produce failure of the specimen is recorded as its stability. (See calibration table for proving ring #25, used in this experiment.)

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3. Hveem Stability Test. At the start of each day's work the speed of the compression machine is checked

by means of the Ames dial and timer, and the lock nut on the speed control lever is adjusted to give a head speed of .05 inch per minute. The displacement of the stabilometer is checked with the dummy specimen and if necessary is adjusted to give 2.00 plus/minus .05 turns.

If the height of the specimen is less than 2 5/16 inches, the body of the stabilometer is lowered by means of the adjustable stage so that the top of the test specimen is 3/16" above the bottom of the upper joint ring. No adjustment need be made for specimens more than 2 15/16". The clamp is then tightened at the base of the shell. The mold containing the specimen is placed on top of the Stabilometer, and by means of the hand lever the specimen is forced out of the mold and into the Stabilometer with care being taken that the specimen goes in straight and is firmly seated.

The follower is placed on top of the specimen and the whole assembly pushed under the cross-hand of the testing press. By means of the displacement pump, the pressure in the body of the Stabilometer is raised until the gauge reads five pounds. The Stabilometer gauge is tapped lightly to assure an accurate reading. The displacement pump angle valve is then closed, being careful that five pounds pressure is maintained. The test load is applied slowly (head speed .05" per minute). The readings of the Stabilometer are recorded at 500 pounds, 1000 pounds, and each

by means of the Ames dial and timer, and the lock nut on the speed control lever is adjusted to give a head speed of .05 inch per minute. The displacement of the stabilometer is checked with the dummy specimen and if necessary is adjusted to give 2.00 plus/minus .05 turns.

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The follower is placed on top of the specimen and the whole assembly pushed under the cross-head of the testing press. By means of the displacement pump, the pressure in the body of the Stabilometer is raised until the gauge reads five pounds. The Stabilometer gauge is tapped lightly to assure an accurate reading. The displacement pump angle valve is then closed, being careful that five pounds pressure is maintained. The test load is applied slowly (head speed .05" per minute). The readings of the Stabilometer are recorded at 500 pounds, 1000 pounds, and each

1000 pounds thereafter. The test load is continued to at least 6000 pounds.

The displacement of the specimen is determined as follows: Immediately after recording the reading under the maximum load, the total on the specimen is reduced to 1000 pounds by lowering the pressure of the testing press. By means of the displacement pump the Stabilometer gauge is set at five pounds. The Ames dial is adjusted to zero by means of the small thumb screw. The displacement pump handle is turned steadily and smoothly clockwise until a pressure of 100 pounds is recorded on the Stabilometer gauge. The exact number of turns required is registered on the Ames dial.

After noting the displacement, the test load is removed and then by means of the displacement pump the pressure on the Stabilometer gauge is reduced to zero. The displacement pump should be backed off an additional turn to facilitate removal of the specimen.

Both the Stabilometer readings and the displacement on the specimen are used in calculating relative stability by the following empirical formula:

$$S = \frac{22.2}{\frac{RD}{400 - R} + .222}$$

S = Relative Stability

R = Stabilometer Reading at 400 pounds per square inch applied load

1000 pounds thereafter. The test load is continued to at least 6000 pounds.

The displacement of the specimen is determined as follows: Immediately after recording the reading under the maximum load, the total on the specimen is reduced to 1000 pounds by lowering the pressure of the testing press. By means of the displacement pump the Stabilometer gauge is set at five pounds. The turns dial is adjusted to zero by means of the small thumb screw. The displacement pump handle is turned steadily and smoothly clockwise until a pressure of 100 pounds is recorded on the Stabilometer gauge. The exact number of turns required is registered on the turns dial.

After noting the displacement, the test load is removed and then by means of the displacement pump the pressure on the Stabilometer gauge is reduced to zero. The displacement pump should be backed off an additional turn to facilitate removal of the specimen.

Both the Stabilometer readings and the displacement on the specimen are used in calculating relative stability by the following empirical formula:

$$S = \frac{22.2}{\frac{RD}{160 - R} + .222}$$

S = Relative Stability

R = Stabilometer Reading at 160 pounds per square inch applied load

D = Turns Displacement on Specimen

This method will in no case give a relative stability of more than 90% if 2.00 turns displacement are used with the dummy specimen (due to the finity value of five pounds initial displacement.)

Stability values in accordance with the above formula may be obtained from Chart Enclosure No. 1.

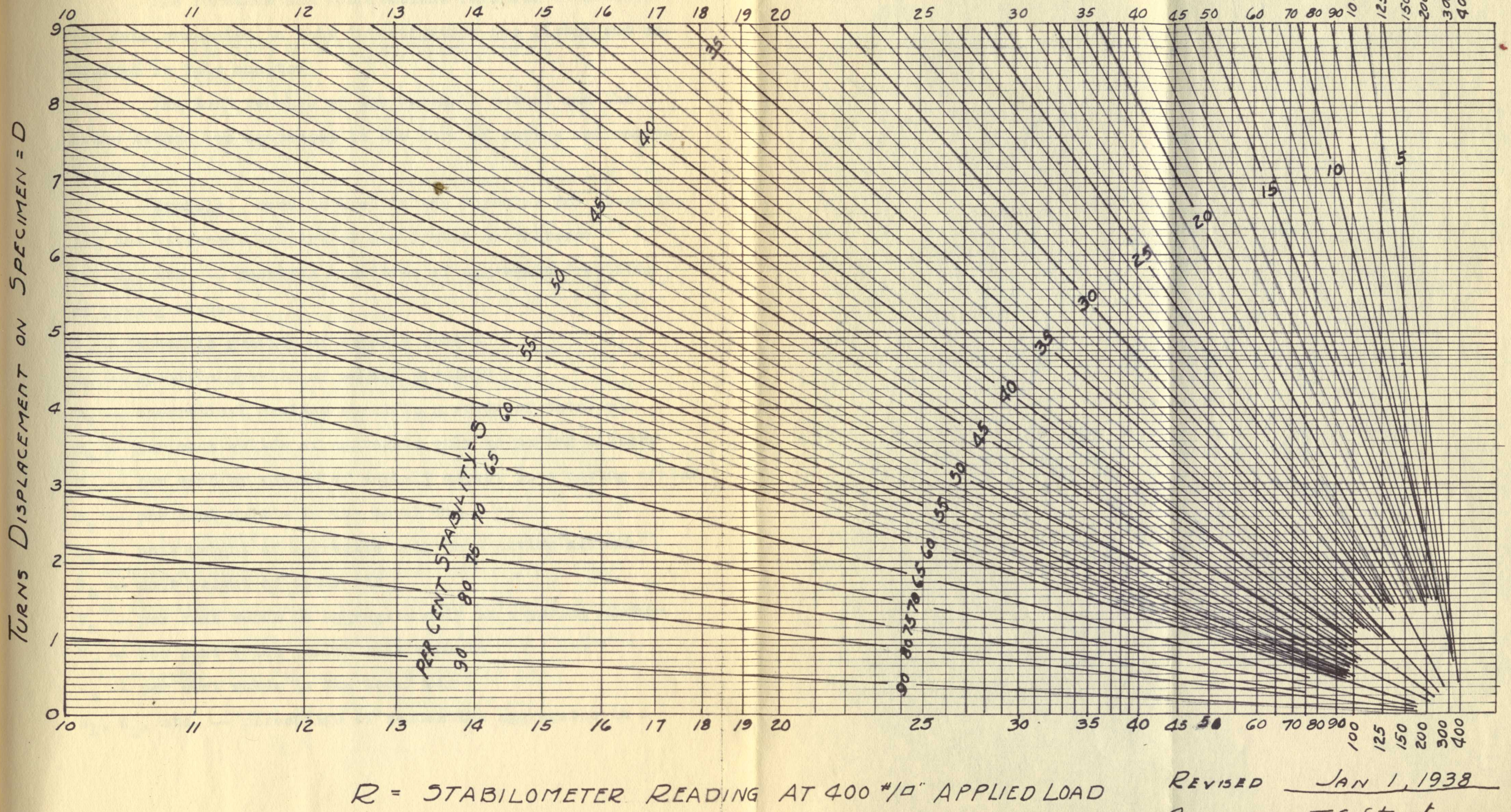
State of California - Division of Highways - Materials & Research Dept.

CONVERSION CHART FOR HVEEM STABILOMETER

RELATIVE STABILITY

FROM STABILOMETER READING AND MEASURED SPECIMEN DISPLACEMENT
(Specimens = 4" Diam. and $2\frac{5}{16}$" net height)

$$S = \frac{22.2}{\left(\frac{RD}{400-R}\right) + .222}$$



REVISED JAN 1, 1938

APPROVED T. E. Stanton
Materials & Research Engr.

Tracad - J. A. Brown
5-9-49

CHAPTER VII

RESULTS OF INVESTIGATION

The formulas and computations required to develop the data presented in this investigation are listed and explained in this chapter.

The test results of the Marshall method and the Hveem method are expressed in the form of curves and computations.

Symbols. Symbols used in the formulas for determining the different properties are listed as follows:

G_1, G_2, etc. -- specific gravities of aggregate fractions of paving mixture.

G_b -- specific gravity of asphalt cement

G_m -- specific gravity of molded specimen

G_t -- theoretical maximum specific gravity of total mix

S_a -- per cent solids of aggregate only in paving mixture

S_b -- per cent by volume of asphalt cement in a paving mixture

S_t -- per cent solids in the total mix

U_a -- unit weight of aggregate only in a paving mixture

U_t -- unit weight of total mix

V_a -- per cent voids in aggregate only in a paving mixture

V_f -- per cent voids filled with asphalt

V_t -- per cent voids in the total mix

W_1, W_2, etc. -- percentage of respective aggregates in a

CHAPTER VII

RESULTS OF INVESTIGATION

The formulas and computations necessary to interpret the data presented in this investigation are listed and explained in this chapter.

The test results of the Marshall method and the Hveem method are expressed in the form of graphs and tabulations.

Symbols. Symbols used in the formulas for computing the different properties are as follows:

G_1, G_2, etc. -- specific gravities of component materials of paving mixture.

G_b -- specific gravity of asphalt cement.

G_m -- specific gravity of molded specimen.

G_t -- theoretical maximum specific gravity of the mix.

S_a -- per cent solids of aggregate in unit volume of mixture.

S_b -- per cent by volume of asphalt cement in unit volume of mix.

S_t -- per cent solids in the total mix.

U_a -- unit weight of aggregate in unit volume of paving mixture.

U_t -- unit weight of total mix.

V_a -- per cent voids in aggregate in unit of paving mixture.

V_f -- per cent voids filled with asphalt.

V_t -- per cent voids in the total mix.

W_1, W_2, etc. -- percentages of component materials by weight.

paving mixture.

W_b -- percent by weight of asphalt cement in a paving mixture.

Formulas and Numerical Examples

1. Specific gravity of asphalt cement.

ASTM D-70-27

$$G_b = \frac{c-a}{(b-a) - (d-c)}$$

where a = weight of empty pycnometer

b = weight of pycnometer filled with distilled water

c = weight of pycnometer half-filled with asphalt

d = weight of pycnometer plus asphalt plus sufficient water to finish filling pycnometer

Numerical example: a = 32.8424 grams, b = 57.5421 grams, c = 45.9431 grams, and d = 57.7990 grams.

$$G_b = \frac{45.9431 - 32.8424}{(57.5421 - 32.8424) - (57.7990 - 45.9431)} = 1.02$$

2. Specific gravity of aggregates. The specific gravities of coarse and fine aggregates (G_1, G_2, etc.) were determined in accordance with the apparent specific gravity test in ASTM Designation C-127-42 and C-128-42 respectively. The following formulas were used:

Coarse Aggregate (ASTM-C127-42)

$$G_1 = \frac{A}{A - C}$$

Where A = weight of oven dry aggregate

C = weight of saturated sample in water

Example: A = 3,000 grams

C = 1,855 grams

$$G = \frac{3,000}{3,000 - 1,855} = 2.62$$

Fine Aggregate (ASTM-C-128-42)

$$G_2 = \frac{A}{F + A - W}$$

Where A = weight of oven dried aggregate

F = weight of flask plus water at twenty degrees Centigrade (68 degrees Farenheit)

W = weight of flask plus aggregate plus sufficient water to finish filling the flask at twenty degrees Centigrade (68 degrees Farenheit)

Example: A = 420 grams

F = 657 grams

W = 916 grams

$$\frac{420}{657 + 420 - 916} = 2.62$$

3. Specific Gravity of Molded Specimens. The specific gravity of the molded specimens (G_m) was determined by the ratio of the weight in air to the volume displaced in water. This method is sufficiently accurate for specimens that are reasonably impermeable to water. The type of asphalt mixture used in this investigation was very impermeable to water, being a dense graded mix.

$$G_m = \frac{a}{a-b}$$

Where a = weight of specimen in air

b = weight of specimen immersed in water at room temperature.

Example: a = 1141.0 grams

b = 653.4 grams

$$G_m = \frac{1141.0}{1141.0 - 653.4} = \frac{1141.0}{487.6} = 2.34$$

4. Theoretical Maximum Specific Gravity

$$G_t = \frac{100}{\frac{W_1}{G_1} + \frac{W_2}{G_2} + \frac{W_b}{G_b}}$$

Example: $W_1 + W_2 = 1098.67$

$G_1 = 2.62$

$G_2 = 2.62$

$W_b = 57.83$

$G_b = 1.02$

$$G_t = \frac{100}{\frac{1098.67}{2.62} + \frac{57.83}{1.02}} = 2.43$$

5. Unit Weight Total Mix. The unit weight of total mix (U_t) expressed in pounds per cubic foot.

Example: $U_t = 62.4G_m$

$G_m = 2.34$

$U_t = 62.4 \times 2.34 = 146$#/cu. ft.

6. Unit Weight of Aggregate Only. $U_a = U_t \frac{(100 - W_b)}{100}$

Example: $U_t = 146$ $W_b = 4.5$

$$U_a = 146 \left(\frac{100 - 4.5}{100}\right) = 139.1$$

7. Per cent Solids Total Mix.

$$S_t = \frac{G_m}{G_t} \; 100$$

Example: $G_m = 2.34$ $G_t = 2.46$

$$S_t = 100 \times \frac{2.34}{2.46} = 95.12 \text{ per cent.}$$

8. Per Cent Voids Total Mix. The per cent voids in the total mix (V_t) is the percentage complement of the per cent solids (S_t) in the total mix.

Example: $S_t = 95.12$

$V_t = 100 - 95.12 = 4.88$ per cent.

9. Per Cent by Volume of Asphalt Cement.

$$S_b = \frac{G_m \times W_b}{G_b}$$

Example: $G_m = 2.34$ $W_b = 4.5$ $G_b = 1.02$

$$S_b = \frac{2.34 \times 4.5}{1.02} = 10.76 \text{ per cent.}$$

10. Per Cent Solids Aggregate Only. $S_a = S_t - S_b$

Example: $S_t = 95.12$ $S_b = 10.76$

$S_a = 95.12 - 1076 = 84.36$ per cent.

11. Per Cent Voids Aggregate Only. The per cent voids in the aggregate only (V_a) is the percentage complement

of the per cent solids in the aggregate only (S_a).

Example: $S_a = 84.36 \quad V_a = 100 - 84.36 = 15.64$

12. Per Cent Voids Filled with Asphalt.

$$V_f = \frac{S_b}{V_a} (100)$$

Example: $S_b = 10.76 \qquad V_a = 15.64$

$$V_f = \frac{10.76}{15.64} \times 100 = 69.8 \text{ per cent.}$$

Experiment Design I-A

TABLE I

PROJECT NO.:
DATE: **March, 1949**
GRADING SERIES: **Dense Graded**
Hot Plant Mix 3/4" Maximum
xxxxxx. - Aggregate

ASPHALTIC CONCRETE
NEW MEXICO STATE HIGHWAY DEPARTMENT
BUREAU OF MATERIALS
UNIVERSITY OF NEW MEXICO, BOX 91
ALBUQUERQUE, N.M.

SP. GR. ACC. = 2.62
SP. GR. A.C. = 1.02
A.C. GRADE = 120 150 penetration

% A. C. BY WT. OF AGGREGATE % A. C. BY WT. OF MIX. #	4.0%		4.5%		5.0%		5.5%		
SPECIMEN NO.	1	2	3	4	5	6	7	8	
(1) Wt. in air	1137.00	1137.80	1141.00	1141.10	1156.50	1156.80	1154.00	1154.0	
(2) Wt. in water	649.70	650.00	653.40	653.50	661.50	661.70	659.30	659.3	
(3) Bulk Vol. = (1)-(2)	487.30	487.80	487.60	487.60	495.00	495.10	494.70	494.7	
(4) Wt. of Agg. = (1) x (100-%A.C.)	1091.52	1092.29	1089.65	1089.75	1098.67	1098.96	1090.53	1090.53	
(5) Wt. A. C. = (1)-(4)	45.48	45.51	51.35	51.35	57.83	57.84	63.97	63.97	
(6) Abs. Vol. Agg. = (4)/G	416.61	416.90	415.89	415.93	419.33	419.45	416.23	416.23	
(7) Abs. Vol. A.C. = (5)/G	44.59	44.61	50.34	50.34	56.70	56.70	62.72	62.72	
(8) Voids in Min. Agg. = (3)-(6) ml.	70.69	70.90	71.71	71.67	75.69	75.65	78.47	78.47	
(8)/3 x 100%	14.51	14.53	14.71	14.69	15.29	15.27	15.86	15.86	
(9) % Agg. Voids filled (7)/8 x 100	63.07	62.92	70.20	70.19	74.91	74.95	79.92	79.92	
	2.33	2.33	2.34	2.34	2.34	2.34	2.33	2.33	
(10) Bulk Density = (1)/3									
(11) Theoretical Density = 100 / (%A/G plus %AC/G)	2.47	2.47	2.46	2.46	2.43	2.43	2.41	2.41	
(12) % Solid Vol. Density = 10/11 x 100	94.45	94.45	95.12	95.12	96.13	96.13	96.68	96.68	
(13) % Voids in Comp. Mix = 100 - (12)	5.55	5.55	4.88	4.88	3.87	3.37	3.32	3.32	
Marshall Stability - Pounds	2010		2460		2442		2410		
Marshall Flow Value	4		4		4½		5		
Hubbard Field Stability - Pounds									
Hveen Field Stability (relative %)		40.0		40.3		41.1		38.4	
Weight per cu. ft. Lbs.	145.58	145.6	146.01	146.0	145.77	145.8	145.39	145.40	
Height of Specimen	2 7/16"	2 1/2"	2 7/16"	2 7/16"	2 7/16"	2 7/16"	2 7/16"	2 7/16"	

DESIGN I-A 3/4" Maximum Aggregate

Data to support Hveem Stability Test.

Specimen #2 4.0% A.C.

Total Load Pounds	P.S.I.	Hveem Dial	Computation
500	40	11.0	$R_1 = \left(1 - \frac{44}{400}\right) \times 100 = 89.0\%$
1000	80	12.0	R_1 = Resistance Value
2000	160	14.0	$R_1 = \left(1 - \frac{Ph}{P_v}\right) \times 100 +$
3000	240	25.0	S = Relative Stability D = Turns Displacement on specimen
4000	320	31.0	
*5000	400	44.0	R = Stabilometer reading at 400 P.S.I. applied Load.
6000	480	56.0	D = 2.70 Turns.

$$S = \frac{22.2}{\frac{RD}{400-R} + 0.222} \quad + \quad S = \frac{22.2}{\frac{44 \times 2.7}{400 - 44} + 0.222} = 40.0$$

Specimen #4-4.5% A.C.

Total Load Pounds	P.S.I.	Hveem Dial	Computation
500	40	9.0	$R_1 = \left(1 - \frac{42}{400}\right) \times 100 = 89.5\%$
1000	80	13.0	
2000	160	16.0	$S = \frac{22.2}{\frac{42 \times 2.8}{400 - 42} + 0.222} = 40.3$
3000	240	24.0	R - 42
4000	320	31.	D - 2.8 Turns.
*5000	400	42.	
6000	480	54.0	

Specimen #6 5.0% A.C.

Total Load Pounds	P.S.I.	Hveem Dial
500	40	10.0
1000	80	12.0
2000	160	15.0
3000	240	22.0
4000	320	32.0
*5000	400	40.0
6000	480	57.0

Computation

$R_1 = \frac{(1-40)}{(400)} \times 100 = 90.0\%$

R = 40.0

D = 2.86 Turns.

$S = \dfrac{22.2}{\frac{40 \times 2.86}{400-40} + 0.222} = 41.1$

Specimen #8 5.5% A.C.

Total Load Pounds	P.S.I.	Hveem Dial
500	40	10.0
1000	80	13.0
2000	160	19.0
3000	240	30.0
4000	320	41.0
*5000	400	46.0
6000	480	56.0

Computation

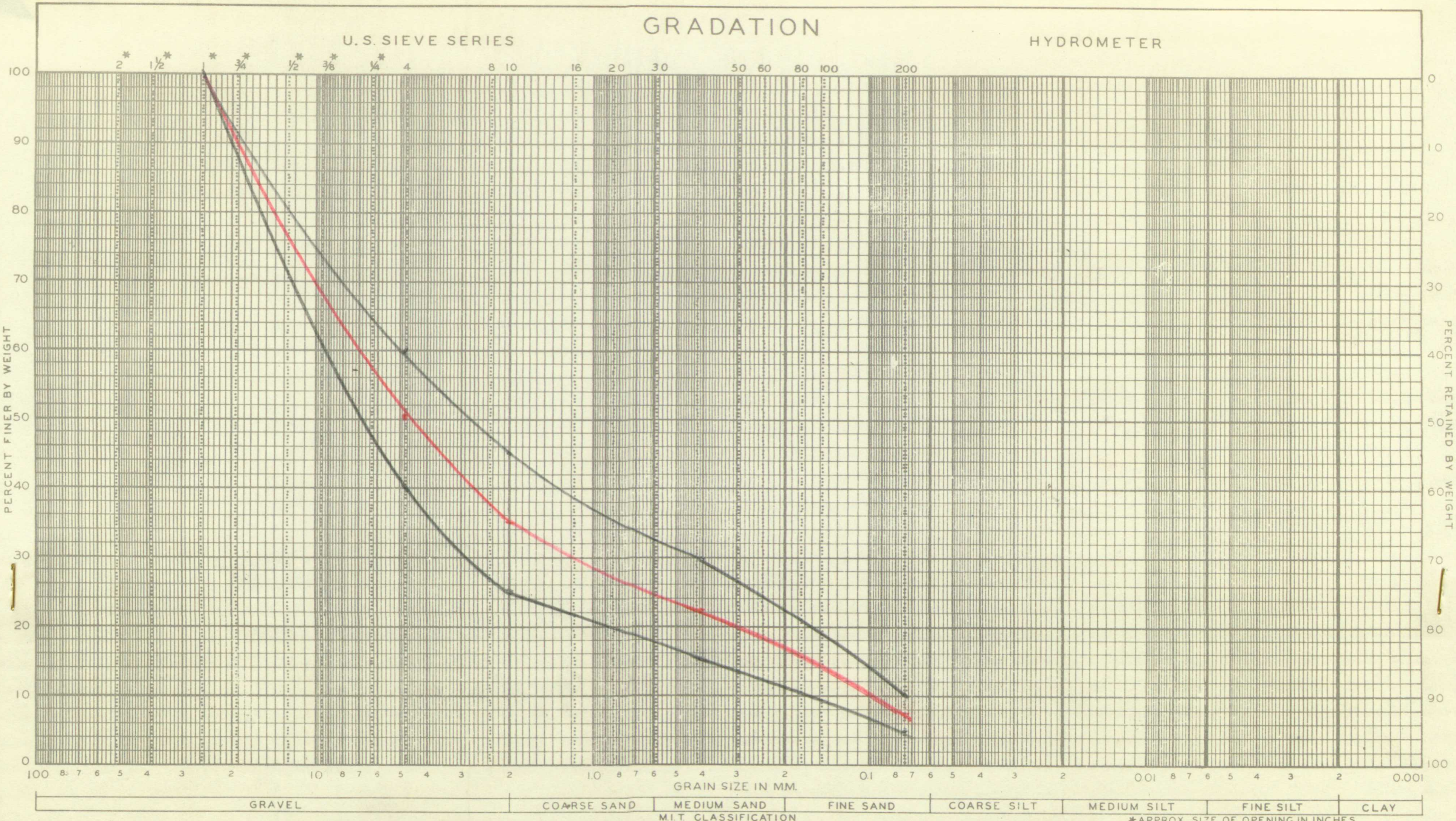
$R_1 = \frac{(1-46)}{(400)} = 88.5\%$

R = 46

D = 2.74 Turns.

$S = \dfrac{22.2}{\frac{46 \times 2.74}{400 - 46} + 0.222} = 38.4$

CHART 2



GRADATION CURVE DESIGN I-A

Sieve Designation	% Passing By Weight	Median
3/4"	100	100
No.4	40-60	50
No.10	25-45	35
No.40	15-30	22.5
No.200	5-10	7.5

PROJECT Tucumcari N.M.
LOCATION
STATION Test Samples from 10
OFFSET Test Holes
HOLE NO. ______ TEST PIT ______
AUGER HOLE ______ UNDISTURBED SAMPLE ______

TABLE II

Experiment Design I-B
PROJECT NO.:
DATE: **March, 1949**
GRADING SERIES: **Dense Graded**
Hot Plant Mix - 1" Maximum Aggregate
Lab. No. -

ASPHALTIC CONCRETE
NEW MEXICO STATE HIGHWAY DEPARTMENT
BUREAU OF MATERIALS
UNIVERSITY OF NEW MEXICO, BOX 91
ALBUQUERQUE, N.M.

SP. GR. ACC. = 2.6
SP. GR. A.C. = 1.02
A.C. GRADE = 120-**penetration**

% A. C. BY WT. OF AGGREGATE / % A. C. BY WT. OF MIX. #	4.0%		4.5%		5.0%		5.5%	
SPECIMEN NO.	1	2	3	4	5	6	7	8
(1) Wt. in air	1127.0	1127.40	1120.0	1120.20	1131.70	1131.60	1135.00	1134.82
(2) Wt. in water	630.0	630.20	631.8	631.90	637.00	636.94	642.80	642.76
(3) Bulk Vol. = (1)-(2)	497.0	497.20	488.20	488.30	494.70	494.66	492.20	492.06
(4) Wt. of Agg. = (1) x (100-%A.C.)	1081.9	1082.30	1069.60	1069.79	1075.10	1075.02	1072.58	1072.40
(5) Wt. A. C. = (1)-(4)	45.1	45.10	50.4	50.41	56.60	56.58	62.42	62.42
(6) Abs. Vol. Agg. = $\frac{(4)}{G}$	412.93	413.09	408.24	408.31	410.34	410.31	409.39	409.31
(7) Abs. Vol. A.C. = $\frac{(5)}{G}$	44.22	44.21	49.41	49.41	55.49	55.47	61.19	61.19
(8) Voids in Min. Agg. = (3)-(6) ml.	84.07	84.11	79.96	79.99	84.36	84.35	82.81	82.75
$\frac{(8)}{3}$ x 100%	16.92	16.91	16.38	16.38	17.05	17.05	16.82	16.81
(9) % Agg. Voids filled $\frac{(7)}{8}$ x 100	52.60	52.56	61.79	61.79	65.78	65.76	73.89	73.94
(10) Bulk Density = $\frac{(1)}{3}$	2.27	2.27	2.29	2.29	2.29	2.29	2.30	2.30
(11) Theoretical Density = $\frac{100}{\frac{\%A}{G} \text{ plus } \frac{\%AC}{G}}$	2.46	2.46	2.45	2.45	2.43	2.43	2.41	2.41
(12) % Solid Vol. Density = $\frac{10}{11}$ x 100	92.27	92.27	93.47	93.48	94.24	94.24	95.44	95.44
(13) % Voids in Comp. Mix = 100 - (12)	7.73	7.73	6.53	6.52	5.76	5.76	4.56	4.56
Marshall Stability - Pounds	1700		1950		2625		2060	
Marshall Flow Value	4		4½		4½		5	
Hubbard Field Stability - Pounds								
Hveen Field Stability (relative %)		41		42		40		30
Aeight per cu. ft. Pounds	141.65	141.70	142.9	143.0	142.9	142.9	143.5	143.52
Height of specimen	2 7/16"	2 7/16"	2 7/16"	2 7/16"	2½"	2½"	2½"	2½"

DESIGN I-B- 12½% of Aggregate Retained on 3/4" Sieve

Data to Support Hveem Stability Test

Specimen #2 4.0% A.C.

Total Load Pounds	P.S.I.	Hveem Dial	Computation
500	40	10.0	
1000	88	12.0	$R_1 = \left(1 - \frac{42}{400}\right) \times 100 = 89.5\%$
2000	160	15.0	R = 42 D = 2.69 Turns
3000	240	24.0	$S = \frac{22.2}{\frac{42 \times 2.69}{400 - 42} + 0.222} = 41.0$
4000	320	30.0	
*5000	400	42.0	
6000	480	55.0	

Specimen #4 4.5% A.C.

Total Load Pounds	P.S.I.	Hveem Dial	Computation
500	40	9.0	$R_1 = \left(1 - \frac{40}{400}\right) \times 100 = 90.0\%$
1000	80	12.0	R = 40 D = 2.80 Turns
2000	160	14.0	$S = \frac{22.2}{\frac{40 \times 2.80}{400 - 40} + 0.222} = 42.0$
3000	240	24.0	
4000	320	29.0	
*5000	400	40.0	
6000	480	56.0	

Specimen #6 5.0% A.C.

Total Load Pounds	P.S.I.	Hveem Dial
500	40	10.0
1000	80	12.0
2000	160	16.0
3000	240	23.0
4000	320	31.0
*5000	400	42.0
6000	480	56.0

Computation

$$R_1 = \left(1 - \frac{42}{400}\right) \times 100 = 89.5\%$$

R = 42 D = 2.87 Turns

$$S = \frac{22.2}{\frac{42 \times 2.87}{400-42} + 0.222} = 42.0$$

Specimen #8 5.5% A.C.

Total Load Pounds	P.S.I.	Hveem Dial
500	40	10.0
1000	80	14.0
2000	160	20.0
3000	240	30.0
4000	320	46.0
*5000	400	66.0
6000	480	86.0

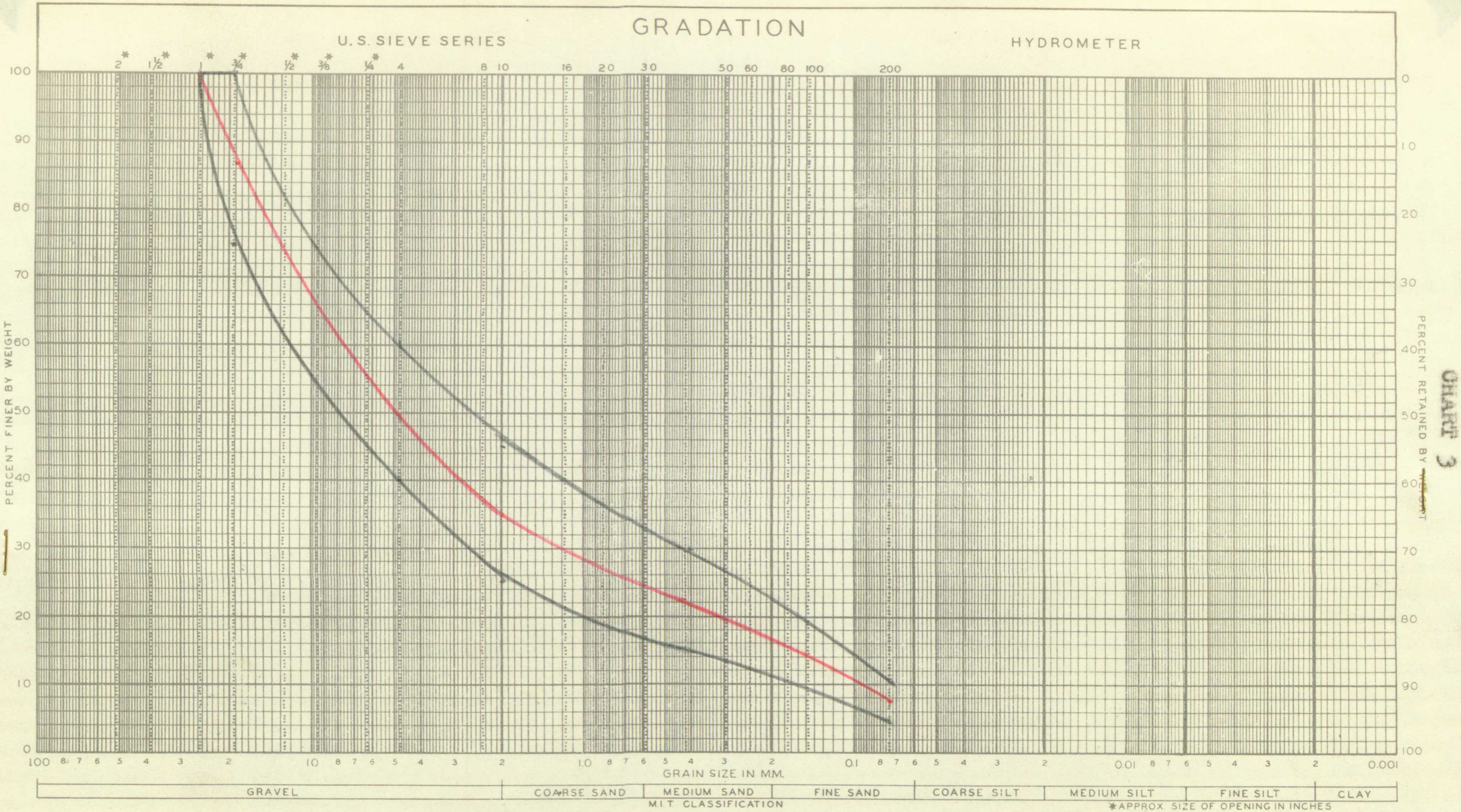
Computation

$$R_1 = \left(1 - \frac{66}{400}\right) \times 100 = 83.5\%$$

R = 66 D = 2.68 Turns

$$S = \frac{22.2}{\frac{66 \times 2.68}{400-66} + 0.222} = 30.0$$

CHART 3



GRADATION CURVE DESIGN I-B

Sieve Designation	% Passing By Weight	Median
1"	100	100.0
3/4"	75-100	87.5
No.4	40-60	50.0
No.10	25-45	35.0
No.40	15-30	22.5
No.200	5-10	7.5

PROJECT Tucumcari, N.M.
LOCATION
STATION Test Samples From 10
OFFSET Test Holes.
HOLE NO. ____ TEST PIT ____
AUGER HOLE ____ UNDISTURBED SAMPLE ____

Sample No. I-A

GRADING CHART FOR BITUMINOUS MIXTURES.

Maximum Size Agg = ~~1"~~ 3/4"

Red Line Denotes Gradation Design- I-A

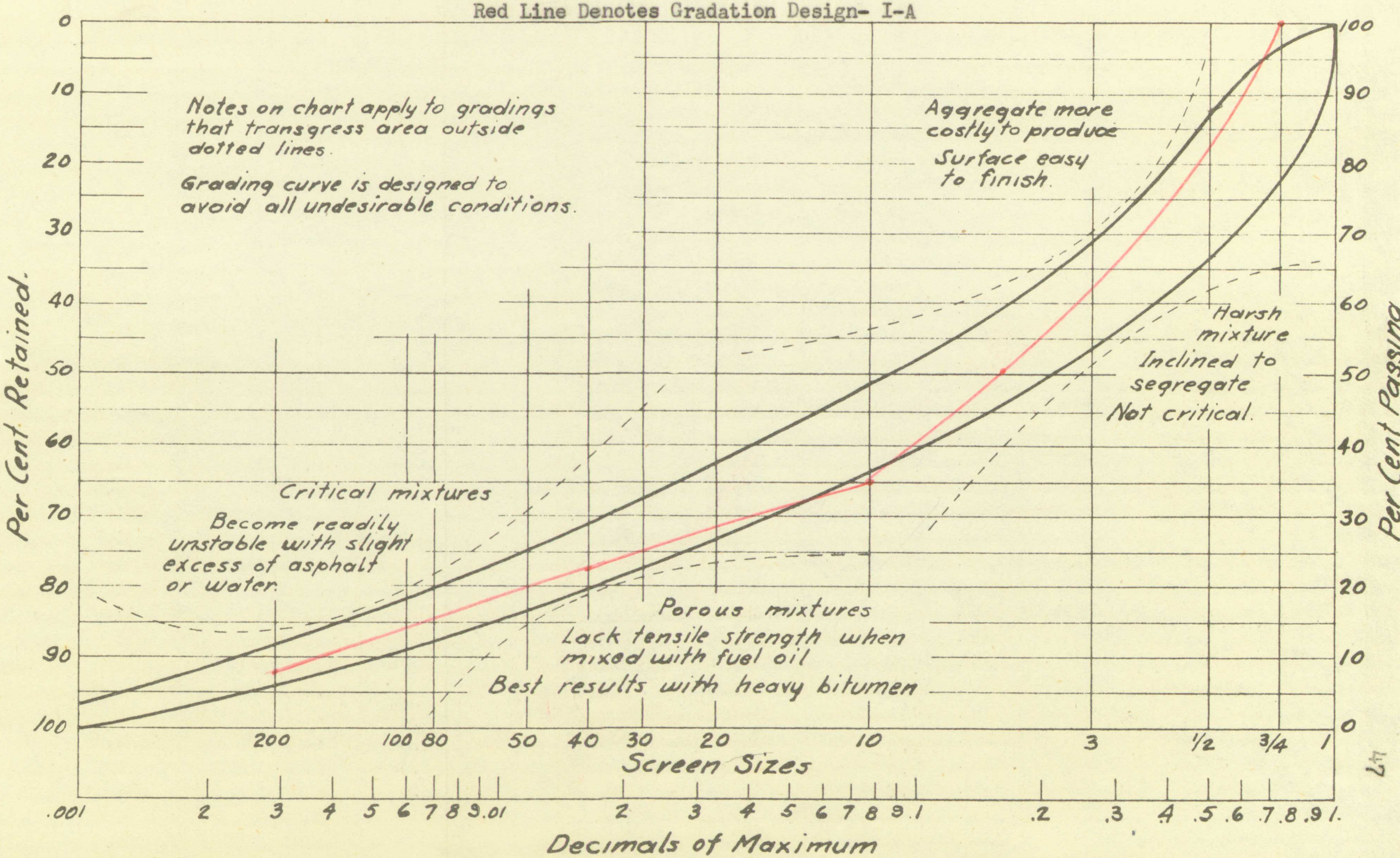


CHART 5

Sample No. I-B

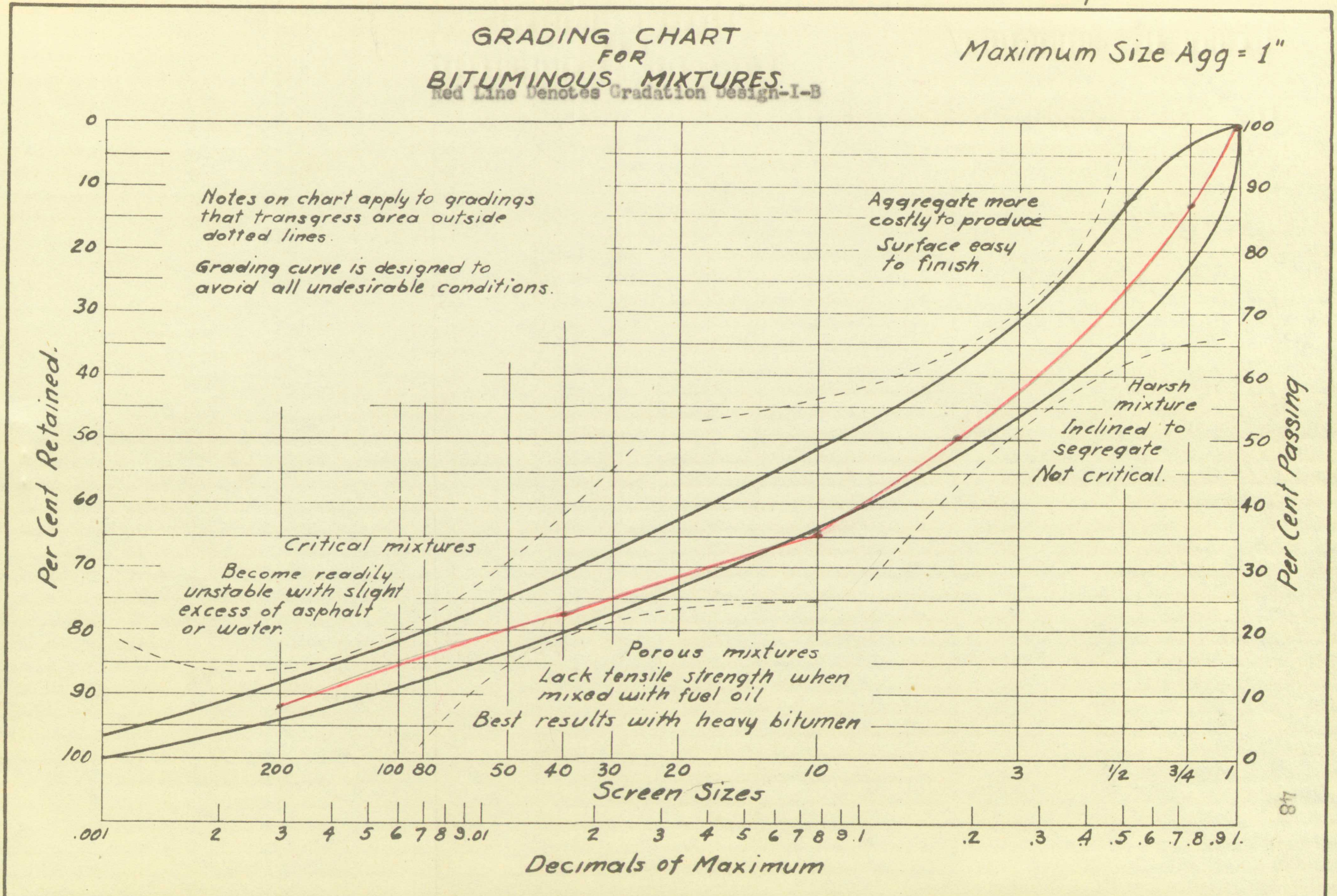


TABLE III

MARSHALL STABILITY METHOD FOR THE DESIGN AND CONTROL OF ASPHALT PAVING MIXTURES

CALIBRATION TABLE FOR PROVING RING NO. 25

Dial Reading	Pounds	Dial Reading	Pounds	Dial Reading	Pounds	Dial Reading	Pounds
0	0	56.5	540	200.5	1950	416.0	4050
1.0	10	58.5	560	205.0	2000	422.0	4100
2.0	20	60.5	580	209.5	2050	428.0	4150
3.0	30	62.5	600	214.0	2100	432.5	4200
4.0	40	64.0	620	218.5	2150	437.5	4250
5.0	50	66.0	640	222.5	2200	442.5	4300
6.0	60	68.0	660	227.5	2250	447.5	4350
7.0	70	70.0	680	232.5	2300	452.5	4400
8.0	80	72.5	700	237.5	2350	457.0	4450
9.0	90	74.0	720	242.5	2400	461.5	4500
10.0	100	76.0	740	248.0	2450	466.5	4550
11.0	110	78.0	760	253.0	2500	472.0	4600
12.0	120	79.5	780	258.5	2550	477.5	4650
13.0	130	81.5	800	263.0	2600	482.5	4700
14.0	140	83.5	820	267.0	2650	487.0	4750
15.0	150	85.5	840	271.5	2700	491.5	4800
16.0	160	87.5	860	276.5	2750	496.0	4850
17.0	170	89.5	880	282.5	2800	501.0	4900
18.0	180	91.5	900	288.0	2850	506.5	4950
19.0	190	93.5	920	293.5	2900	511.5	5000
20.0	200	95.5	940	298.5	2950	516.5	5050
21.0	210	97.5	960	304.0	3000	521.5	5100
22.5	220	100.0	980	309.0	3050	526.5	5150
23.5	230	102.0	1000	314.0	3100	532.0	5200
24.5	240	107.5	1050	319.0	3150	538.3	5250
25.5	250	113.5	1100	324.0	3200	545.5	5300
26.5	260	119.0	1150	329.5	3250	551.5	5350
27.5	270	124.5	1200	334.5	3300	557.0	5400
28.5	280	131.5	1250	340.0	3350	563.0	5450
30.0	290	136.5	1300	345.0	3400	568.5	5500
31.0	300	141.5	1350	351.0	3450	574.0	5550
33.0	320	147.0	1400	357.5	3500	579.5	5600
35.0	340	151.5	1450	363.5	3550	584.0	5650
37.5	360	155.5	1500	369.0	3600	588.5	5700
40.0	380	160.5	1550	374.0	3650	593.5	5750
42.0	400	165.5	1600	380.0	3700	599.0	5800
44.5	420	171.5	1650	385.0	3750	605.0	5850
47.0	440	176.0	1700	390.0	3800	611.0	5900
48.5	460	181.0	1750	395.0	3850	617.5	5950
50.5	480	186.5	1800	400.5	3900	623.5	6000
52.5	500	191.5	1850	405.5	3950		
54.5	520	196.0	1900	411.0	4000		

TABLE IV

STABILITY CORRELATION RATIO

Volume of Specimen in Cubic Centimeters	Approximate Thickness of Specimen in Inches	Correlation Ratio
200 - 213	1	5.56
214 - 225	1-1/16	5.00
226 - 237	1-1/8	4.55
238 - 250	1-3/16	4.17
251 - 264	1-1/4	3.85
265 - 276	1-5/16	3.57
277 - 289	1-3/8	3.33
290 - 301	1-7/16	3.03
302 - 316	1-1/2	2.78
317 - 328	1-9/16	2.50
329 - 340	1-5/8	2.27
341 - 353	1-11/16	2.08
354 - 367	1-3/4	1.92
368 - 379	1-13/16	1.79
380 - 393	1-7/8	1.67
393 - 405	1-15/16	1.56
406 - 420	2	1.47
421 - 431	2-1/16	1.39
432 - 443	2-1/8	1.32
444 - 456	2-3/16	1.25
457 - 470	2-1/4	1.19
471 - 482	2-5/16	1.14
483 - 495	2-3/8	1.09
496 - 508	2-7/16	1.04
509 - 522	2-1/2	1.00
523 - 535	2-9/16	0.96
536 - 546	2-5/8	0.93
547 - 559	2-11/16	0.89
560 - 573	2-3/4	0.86
574 - 585	2-13/16	0.83
586 - 598	2-7/8	0.81
599 - 610	2-15/16	0.76
611 - 625	3	

NOTES: 1. The measured stability of a specimen multiplied by the ratio for the thickness of the specimen equals the corrected stability for a 2-1/2-in. specimen.

2. Volume-thickness relationship is based on a specimen diameter of 4 inches.

CHAPTER VIII

INTERPRETATION OF TEST RESULTS

<u>Marshall Test Properties</u>. Four specimens were prepared and tested, one for each asphalt content, and the test values recorded, using the formulas as derived in Chapter VII. The following test properties were computed for each asphalt content:

1. Weight in air
2. Weight in water
3. Bulk volume
4. Weight of aggregate
5. Weight of asphaltic cement
6. Absolute volume of aggregates
7. Absolute volume of asphaltic cement
8. Voids in the mineral aggregate
9. Per cent voids filled with asphalt
10. Bulk density
11. Theoretical density
12. Per cent solid volume density
13. Per cent voids in composite mix
14. Marshall stability--pounds
15. Marshall flow value--1/32 inch
16. Weight per cubic foot--pounds
17. Height of specimen.

Test Properties Curves. For the determination of the optimum asphalt content, the following five test properties were used:

1. Stability
2. Flow
3. Per cent solid volume density
4. Weight per cubic foot (unit weight)
5. Per cent total voids filled with asphalt.

The above five test properties are plotted versus per cent of asphalt cement by weight. These curves are included in the latter part of this chapter.

In general the curves which were plotted for experiment I-A (maximum 3/4" material) have the following characteristics:

1. Stability increases with increasing asphalt content, reaching a maximum value at 4.5% asphalt cement (by weight), beyond which further increases in asphalt show a decrease in stability. The decrease in stability is very slight between 4.5% and 5% asphalt cement content (by weight). There is a marked decrease in stability between 5% and 5.5% asphalt content. The optimum asphalt as derived from a study of the curve appears to be between 4.5% and 5% asphalt content. All stabilities are above the minimum of 1500 pounds.

2. The flow curve shows an increase with the increasing asphalt content. There is no change in value between

4.0% and 4.5%, but there is a rapid rise between 4.5% and 5.0% and the rise continues at about the same rate to 5.5% asphalt. This curve indicates that the flow is gradual at low asphalt contents but rises rapidly as the per cent of asphalt is increased. The maximum value of six was not reached with any of the four specimens. If the curve had been projected beyond the 5.5% asphalt content, the results indicate that the maximum flow value would occur at approximately 6.3% asphalt content.

3. The curve which shows the relation between the per cent solid volume density and the per cent of asphalt cement (by weight) shows a uniform increase in density with an increase of asphalt cement. The values as obtained in this experiment (I-A) ranged between 94.5 for an asphalt content of 4.0% to 96.7% for an asphalt content of 5.5%.

In terms of total voids in the mix, this range would be from 3.3% for the 5.5% asphalt content to 5.5% for the 4.0% asphalt content. The per cent voids total mix should be not less than 3% nor more than 5%, the median being 4%.

A study of the projection of the curve indicates that had a 6% asphalt been used the per cent solid volume density would have been 97.3% -- or 2.7% voids in the total mix.

4. The unit weight (pounds per cubic foot) versus per cent asphalt cement (by weight) curve shows an increase in asphalt up to a maximum, then a decrease in weight with

4.0% and 4.5%, but there is a rapid rise between 4.5% and 5.0% and the rise continues at about the same rate to 5.5% asphalt. This curve indicates that the flow is gradual at low asphalt contents but rises rapidly as the per cent of asphalt is increased. The maximum value of mix was not reached with any of the four specimens. If the curve had been projected beyond the 5.5% asphalt content, the results indicate that the maximum flow value would occur at approximately 6.3% asphalt content.

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4. The unit weight (pounds per cubic foot) versus per cent asphalt cement (by weight) curve shows an increase in asphalt up to a maximum, then a decrease in weight with

increase in asphalt cement content. It will be noted that the increase in weight from an asphalt content of 4.0% to 4.5% is only 0.4 of a pound and the decrease in weight from an asphalt content of 4.5% to 5.5% is only 0.6 of a pound.

5. Per cent total voids filled with asphalt cement versus per cent asphalt cement content (by weight). This curve is practically a straight line; the per cent of total voids filled with asphalt increases in direct proportion to the increase in asphalt content. At 4.0% asphalt content, the curve reveals that only 63% of the total voids are filled with asphalt, whereas at 5.0% asphalt content, 75% of the total voids are filled with asphalt. The relation predicted by this curve is very important as will be explained in Chapter IX.

Selection of Optimum Asphalt Content - Design I-A. The test procedure and computations described for Design I-A have been directed toward furnishing information on a given bituminous mixture such that the proper asphalt content may be selected for satisfactory Hot Plant Mix pavement design. The asphalt content desired, termed the "optimum asphalt," is determined by assigning criteria to certain of the test properties, selecting the asphalt content that satisfies each individual case, and averaging the asphalt content obtained. The average value is the optimum asphalt content. The criteria for satisfactory Hot Plant Mix

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asphaltic concrete pavement has been established by both laboratory tests and tests of the finished pavements which have been subjected to heavy loads and attained additional density due to traffic.

Design Criteria - Dense Graded Asphaltic Concrete - Design I-A

Test property	Limits	Value to be used for selection of optimum asphalt content.
Flow	Less than 6	
Stability	More than 1500	Maximum
Unit weight, total mix		Maximum
Per cent voids, total mix	3-5	4
Per cent voids filled with asphalt	70-80	75

An example of the selection of optimum asphalt content is shown for test results of Design I-A.

Test property	Selected asphalt content
Flow	5.0
Stability	4.5
Unit weight total mix	4.5
Per cent voids total mix	5.0
Per cent voids filled with asphalt	5.0
Average	4.8

Selected asphalt content is 5.0%. Tolerance, depending on field grading of aggregates, is 4.5 to 5.5 per cent asphaltic cement by weight.

<u>Test Properties Curves Design I-B</u> (12% plus 3/4" material). For determination of the optimum asphalt content, the same five tests were used as were used in Design I-A. Each of these test properties are plotted against per cent of asphalt. The out-standing characteristics of the various curves are as follows:

1. The stability increases with increasing asphalt content reaching a maximum at 5% asphalt content, beyond which further increase in asphalt shows a definite decrease in stability. This sharp jump in stability from 4.5% to 5% and the sharp drop in stability from 5% to 5.5% is believed to be due to the grading of the material, but may be due to an error in reading the strain gauge. Design I-A, which is a denser grading, developed on a maximum of 2625 pounds, whereas Design I-B developed a maximum of 2460.

2. The flow curve in Design II-B is more erratic than that in Design I-A. This curve shows a radical rise from 4.0% to 4.5% asphalt and levels off between 4.5% and 5.0% asphalt and then rises abruptly from 5.0% to 5.5%. All specimens are within the maximum flow value of 6.

3. The per cent solid volume density curve is more erratic than the same curve for Design I-A. The slope of the tangent to the curve between 4.0% and 4.5% asphalt content is about as it should be but the curve flattens out between 4.5% and 5.0%. This specimen which contained 12.5% of plus

Test Properties Curves Design I-B (12% plus 3/4" material). For determination of the optimum asphalt content, the same five tests were used as were used in Design I-A. Each of these test properties are plotted against per cent of asphalt. The out-standing characteristics of the various curves are as follows:

1. The stability increases with increasing asphalt content reaching a maximum at 5% asphalt content, beyond which further increase in asphalt shows a definite decrease in stability. This sharp jump in stability from 4.5% to 5% and the sharp drop in stability from 5% to 5.5% is believed to be due to the grading of the material, but may be due to an error in reading the strain gauge. Design I-A, which is a denser grading, developed on a maximum of 2625 pounds, whereas Design I-B developed a maximum of 2450.

2. The flow curve in Design I-B is more erratic than that in Design I-A. This curve shows a radical rise from 4.0% to 4.5% asphalt and levels off between 4.5% and 5.0% asphalt and then rises abruptly from 5.0% to 5.5%. All specimens are within the maximum flow value of 5.

3. The per cent solid volume density curve is more erratic than the same curve for Design I-A. The slope of the tangent to the curve between 4.0% and 4.5% asphalt content is about as it should be but the curve flattens out between 4.5% and 5.0%. This specimen which contained 12.5% of plus

3/4" aggregate did not develop the density that Design I-A (maximum 3/4" material) did, which shows the difference due to gradation of the material.

4. A study of the unit weight (pounds per cubic foot) curve reveals that due to a low density there is no peak in the curve nor maximum at which the weight should drop with an increase in asphalt. This condition is due to gap grading of the material.

5. The per cent total voids filled with asphalt reveals an open or irregular grading. The per cent of voids filled with asphalt is very low; the minimum of 70% is not reached until an asphalt content of 5.25 is used.

<u>Design Criteria Hot Plant Mix Asphaltic Concrete Design I-B</u>

Test property	Limits	Value to be used for selection of optimum asphalt content
Flow	Less than 6	
Stability	More than 1500	Maximum
Unit weight, total mix		Maximum
Per cent voids total mix	3-5	4
Per cent voids filled with asphalt	70-80	75

An example of the selection of optimum asphalt content is shown for test results of Design I-B.

Test property	Selected asphalt content percent
Flow	5.0
Stability	5.0
Unit weight total mix	5.5
Voids total mix	5.5
Voids filled with asphalt	5.5
Average	5.3

Selected asphalt content is 5.5. Tolerance depending on field grading of aggregate is 5.0% to 6.0%.

Hveem Test Properties Designs I-A and I-B. Four specimens were prepared and tested, one for each asphalt content (4.0%, 4.5%, 5.0%, 5.5%) and the test values recorded. The same test properties were computed for the Hveem specimens as were computed for the Marshall specimens with the exception of the Flow Value.

There was no Hveem cohasiometer available at the time these tests were made, so the Hveem criteria of design was not followed. The Texas method of design using a standard Hveem Stabilometer was followed. This method was taken from the Texas State Highway Department Construction Bulletin C-14, October, 1947.

The Texas design criteria for the optimum amount of asphalt cement content is based on the relative stability and the solid volume density of the specimen.

The following requirements for density and stability

have been set up for Designs I-A and I-B:

Type of Mixture	Density (%) Min.	Max.	Optimum	Stability Minimum
Hot Plant Mix Asphaltic Concrete	94.0	98.0	96.0	35

Design I-A. The criteria for the Texas Method of design using the Hveem stabilometer values and per cent of density of the specimen are illustrated by a graph combining both Hveem stability values against per cent asphalt cement (by weight) and per cent density against per cent asphalt. To arrive at optimum asphalt content to be used, the following procedure is followed: Draw a horizontal dashed line through 96, or desired density, on the ordinate of the density curve, at the point at which this line intersects the density curve; drop a perpendicular dashed line down to an intersection of the stability curve; at the point at which the perpendicular intersects the stability curve draw a horizontal dashed line to intersect the ordinate representing the stability values. If the stability is above 35, the asphalt content will be the per cent as shown by the vertical dashed line projected down from the density curve.

Optimum Asphalt Content for Design I-A

Optimum per cent density	Optimum asphalt content	Stability
96	5.0	41

Optimum Asphalt Content for Design I-B

Minimum per cent density	Optimum asphalt content	Stability
94.4	5.0	40

The optimum asphalt content and density for Design I-A checks the Marshall Method. It is noted that the optimum density of 96% is used. The optimum asphalt content in Design I-B does not check the Marshall Method for Design I-B. It is noted that had an optimum asphalt content of 5.5% been selected, as revealed by the Marshall Method, the stability would have been too low and would have fallen in the cross hatched area and would have been 30.

The Hveem and Marshall Methods both reveal that Design I-B does not develop the required design values. Design I-B was rejected and Design I-A used as the approved design.

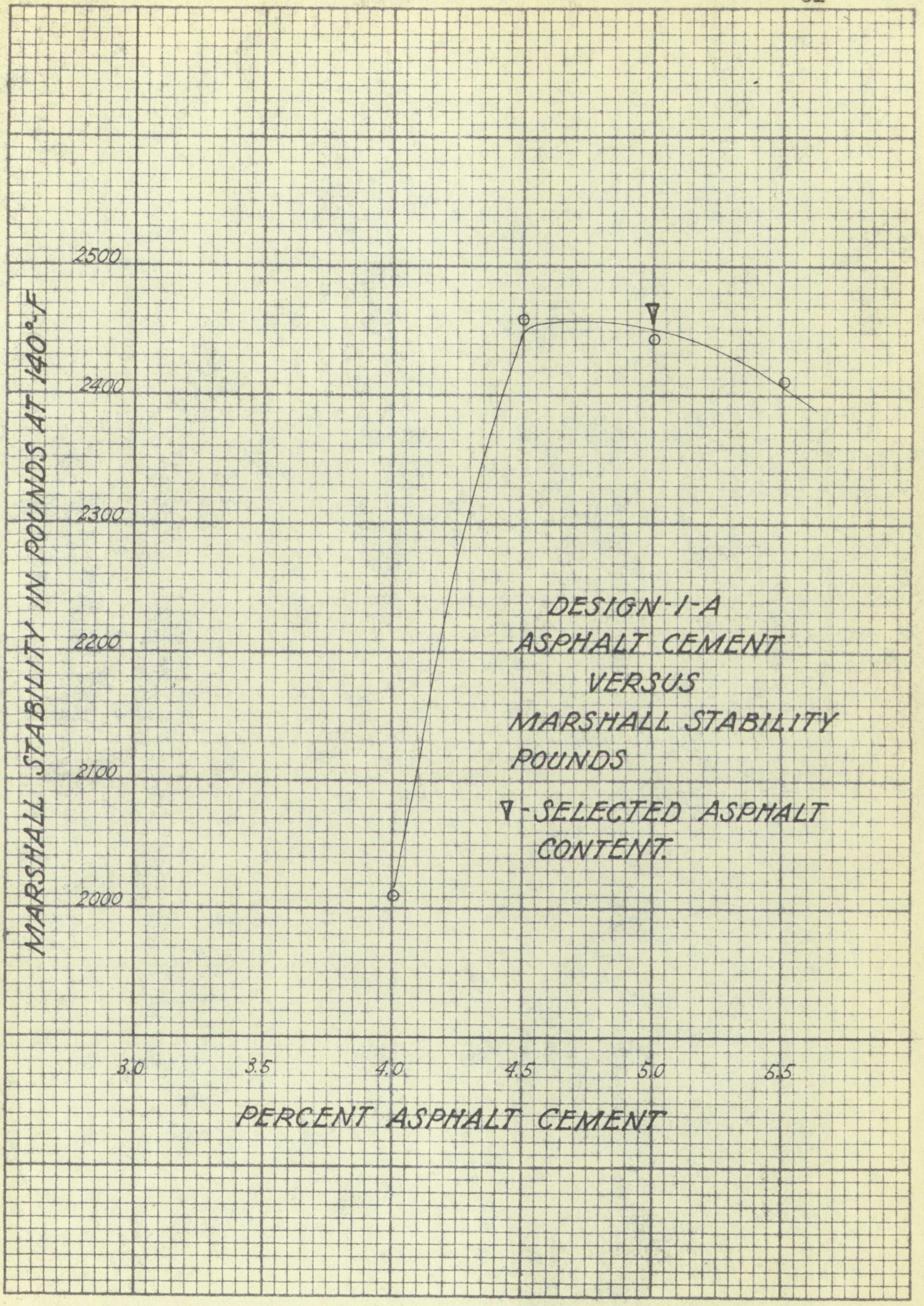
[illegible] Design [illegible]

Minimum [illegible] Design [illegible]

The [illegible] checks the Marshall Method of Test [illegible] density of [illegible] Design I-3 does not meet the [illegible] It is noted that [illegible] selected, as previously [illegible] would have been the [illegible] batched [illegible]

The [illegible] Design I-3 does not [illegible] Design I-3 was [illegible] design.

CHART 6



MARSHALL STABILITY IN POUNDS AT 140°F
2500
2400
2300
2200
2100
2000
3.0
3.5
4.0
4.5
5.0
5.5
PERCENT ASPHALT CEMENT
DESIGN-I-A
ASPHALT CEMENT
VERSUS
MARSHALL STABILITY
POUNDS
▽-SELECTED ASPHALT
CONTENT.

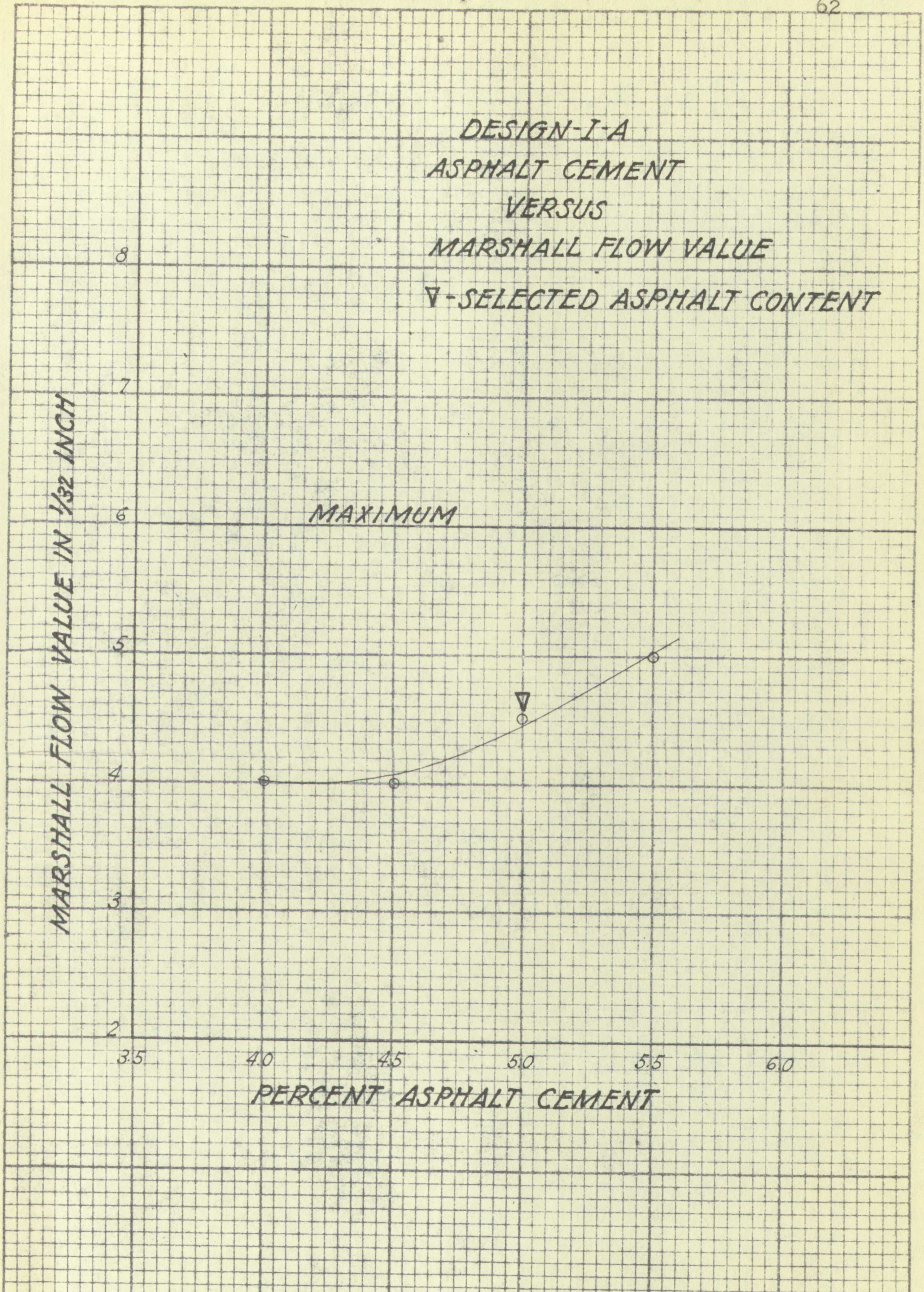

DESIGN-I-A
ASPHALT CEMENT
VERSUS
MARSHALL FLOW VALUE
∇-SELECTED ASPHALT CONTENT
MAXIMUM
MARSHALL FLOW VALUE IN 1/32 INCH
8
7
6
5
4
3
2
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT

CHART 8

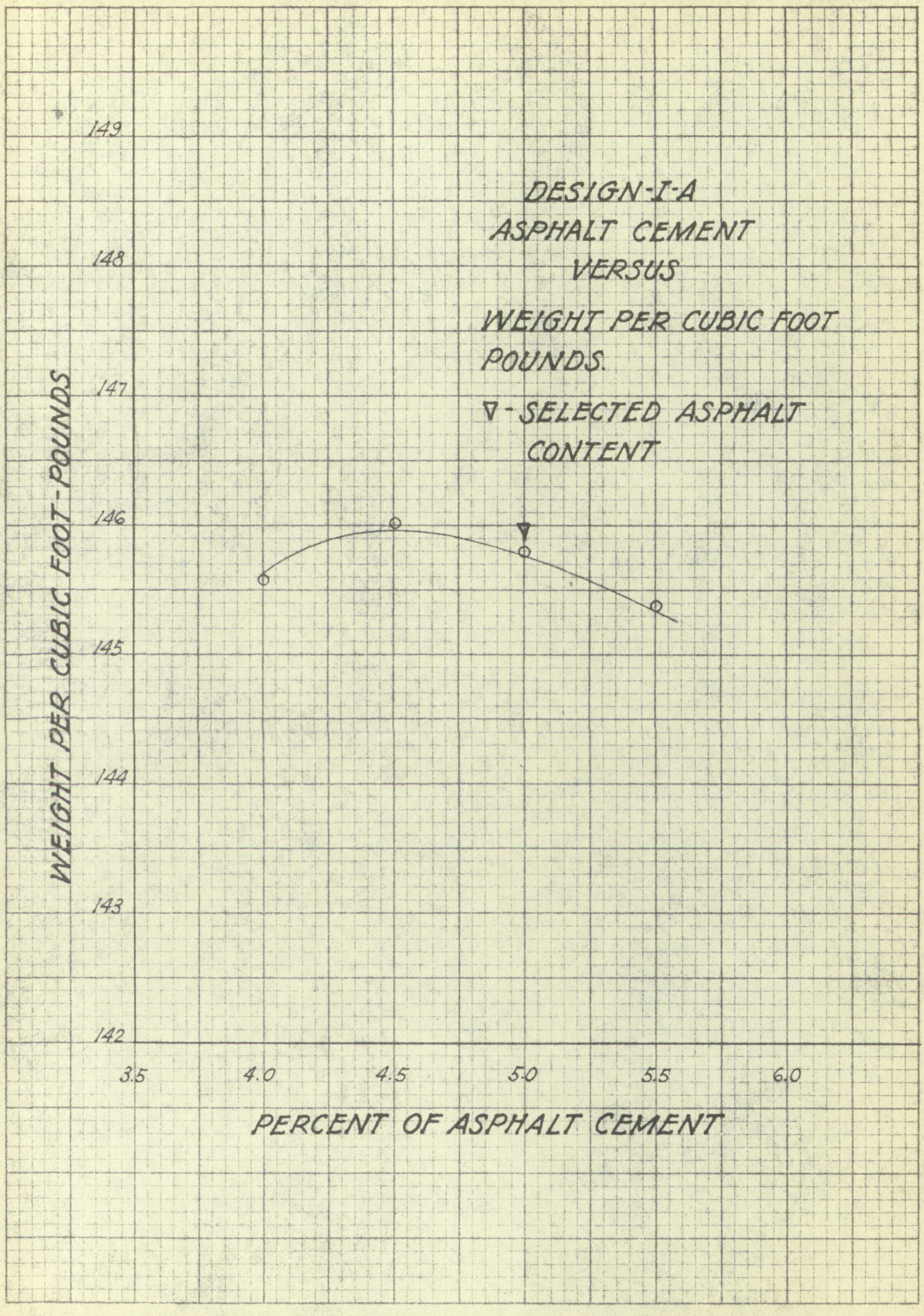
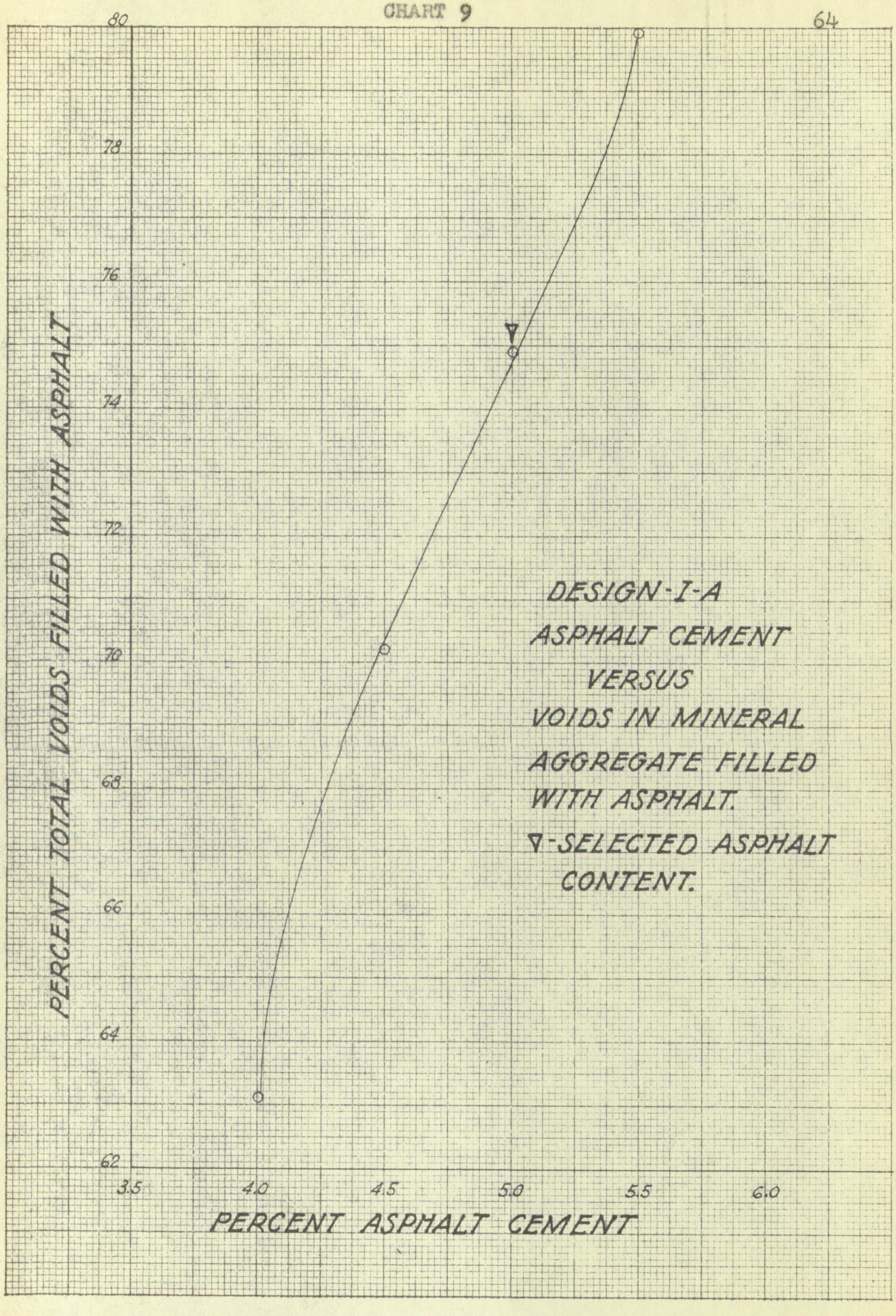
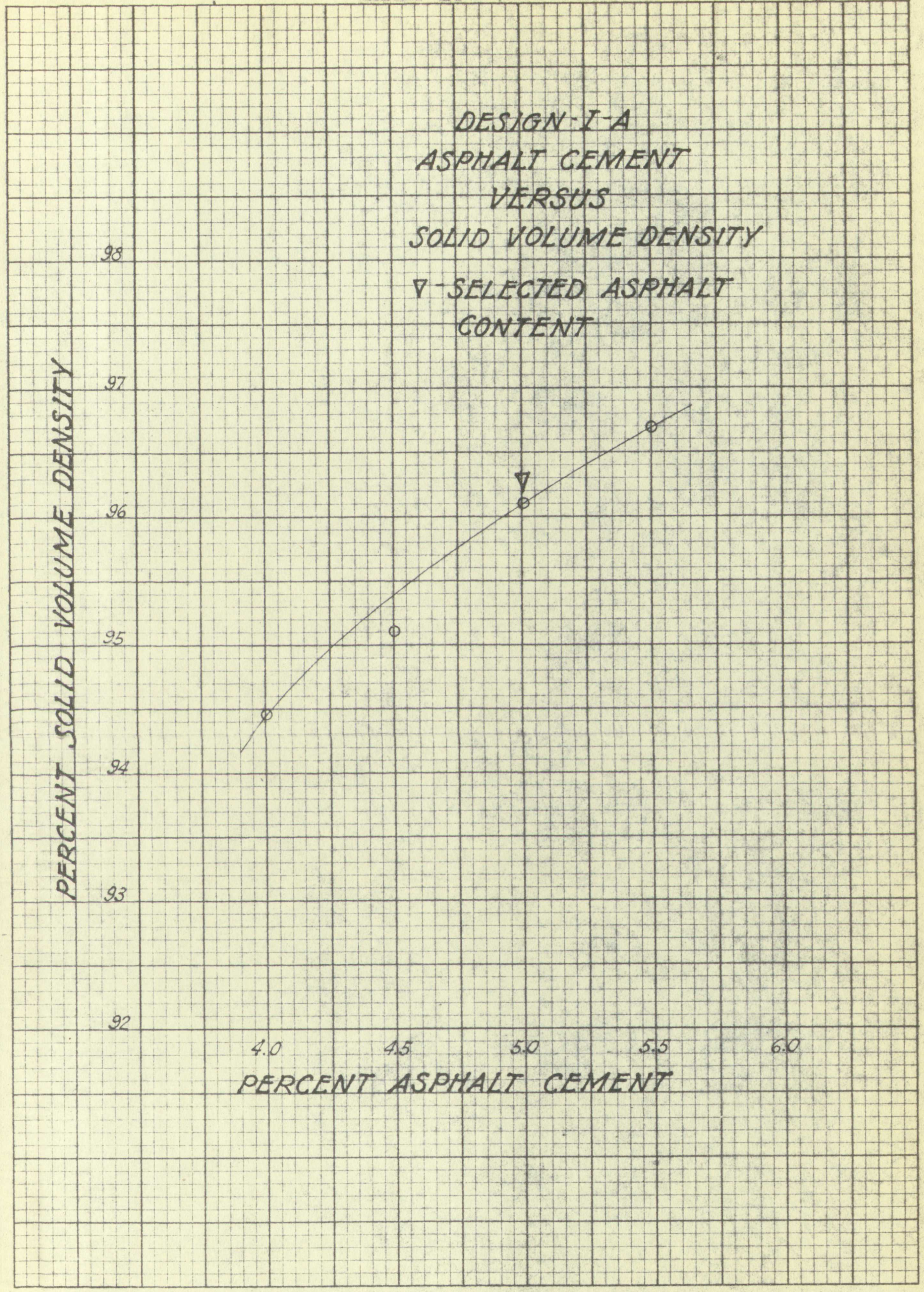
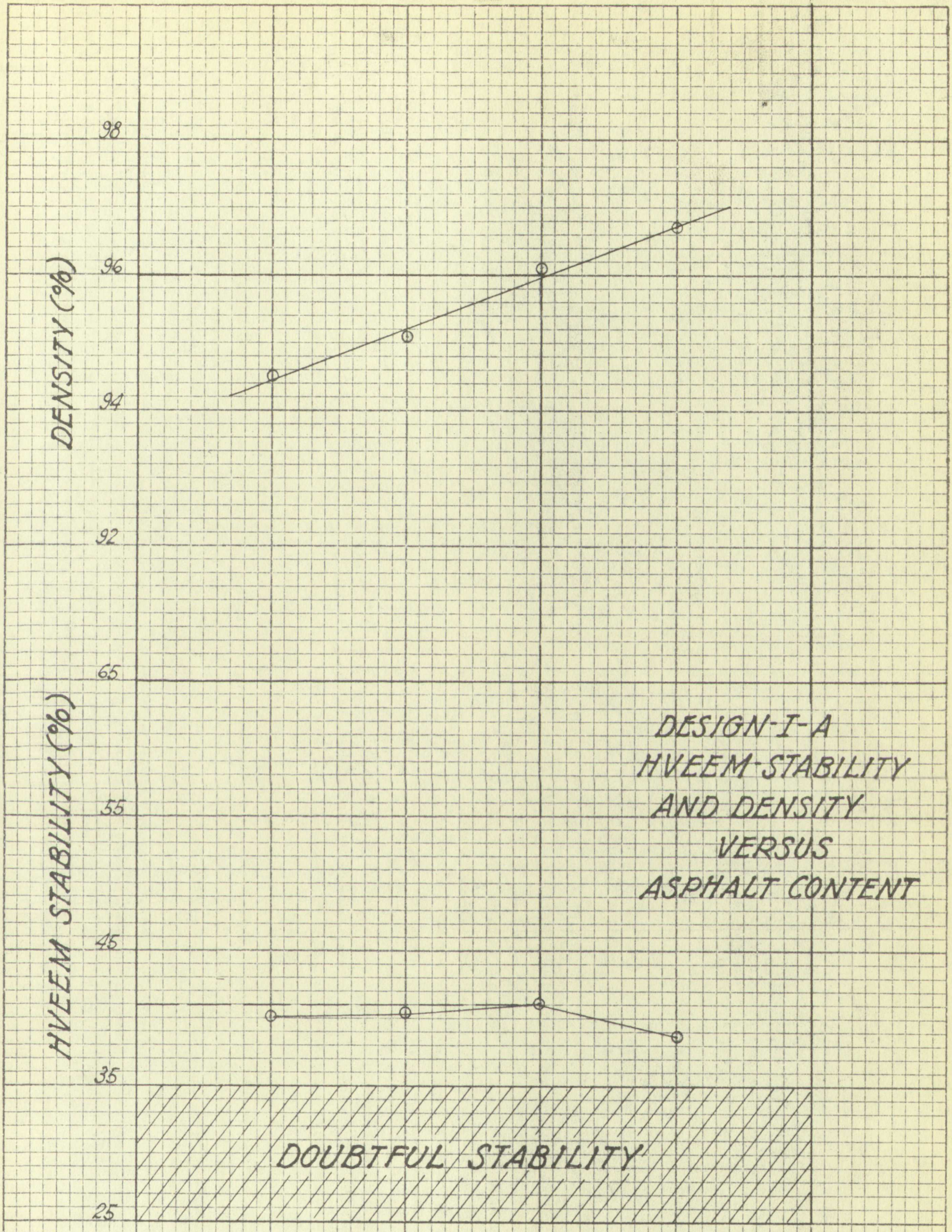

DESIGN-I-A
ASPHALT CEMENT
VERSUS
WEIGHT PER CUBIC FOOT
POUNDS.
∇ - SELECTED ASPHALT
CONTENT
WEIGHT PER CUBIC FOOT-POUNDS
149
148
147
146
145
144
143
142
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT OF ASPHALT CEMENT

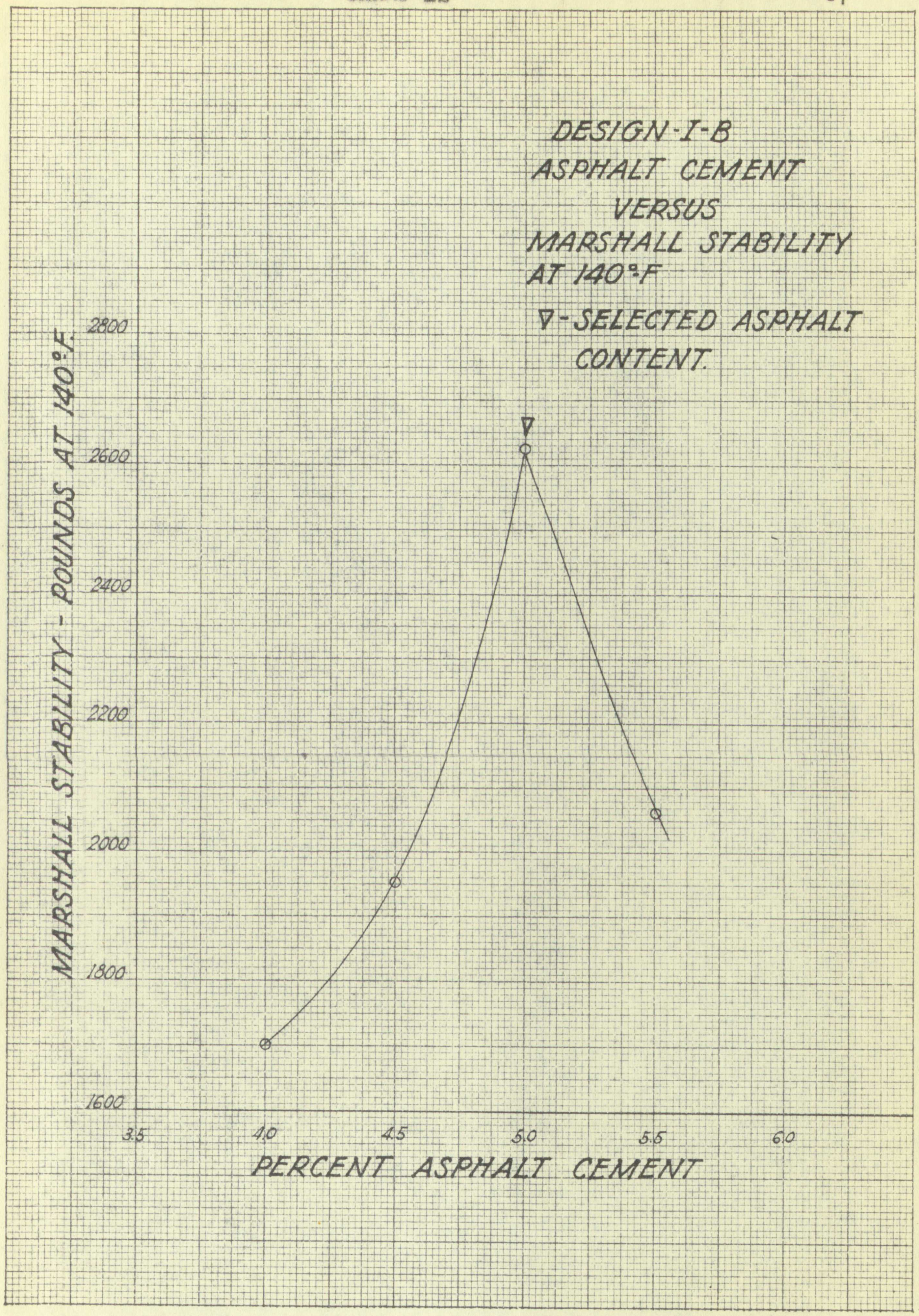
CHART 9

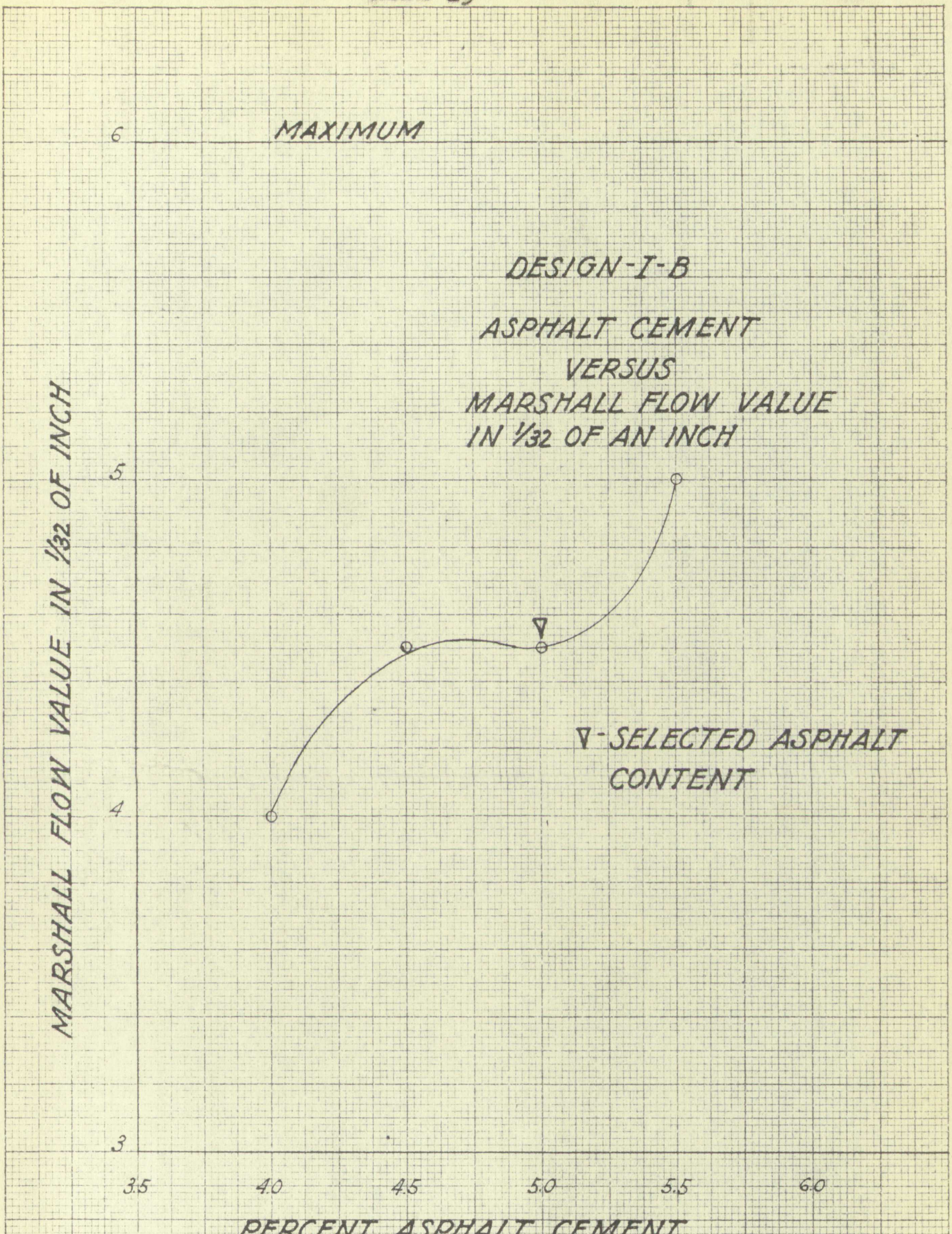


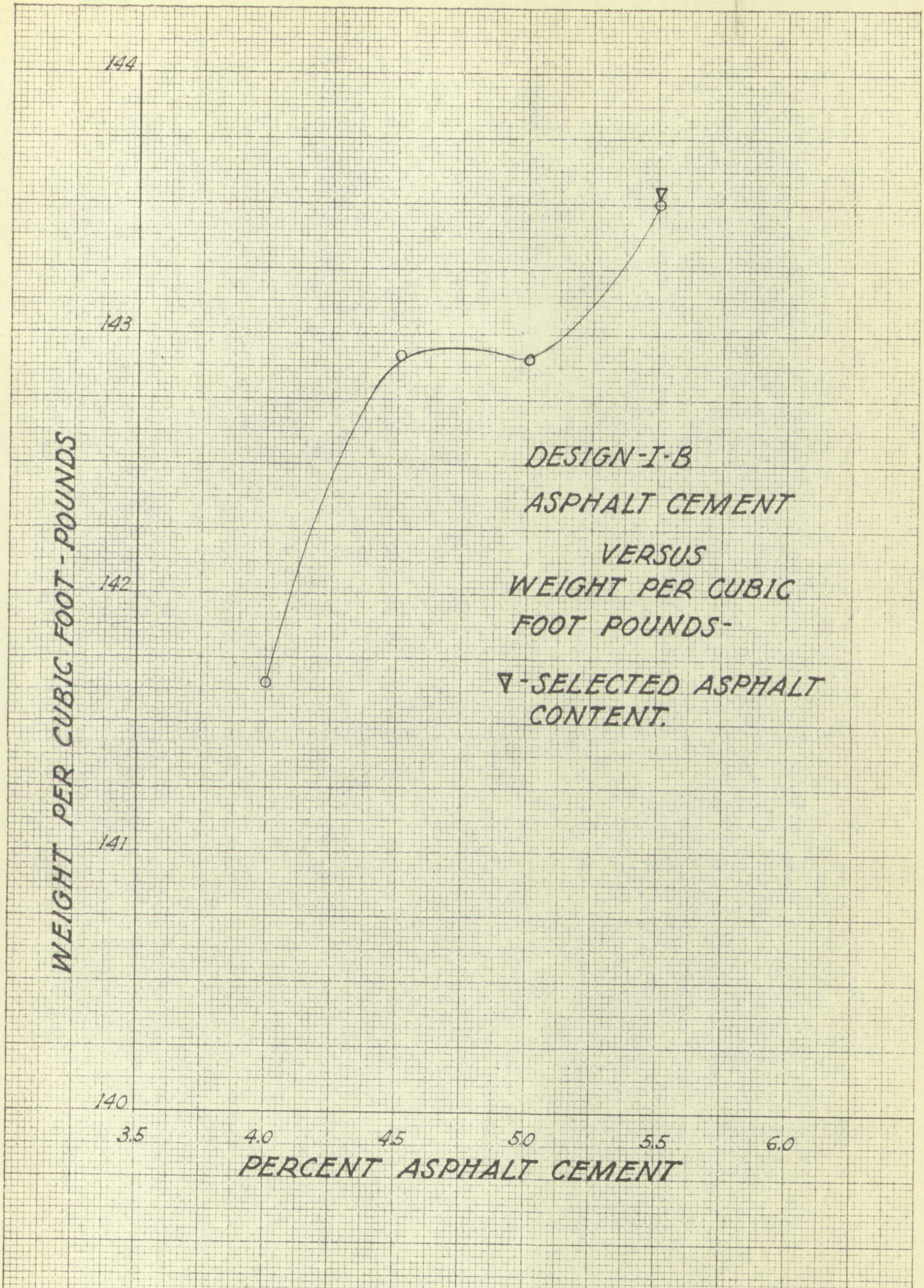
80
78
76
74
72
70
68
66
64
62
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT TOTAL VOIDS FILLED WITH ASPHALT
PERCENT ASPHALT CEMENT
DESIGN-I-A
ASPHALT CEMENT
VERSUS
VOIDS IN MINERAL
AGGREGATE FILLED
WITH ASPHALT.
∇-SELECTED ASPHALT
CONTENT.

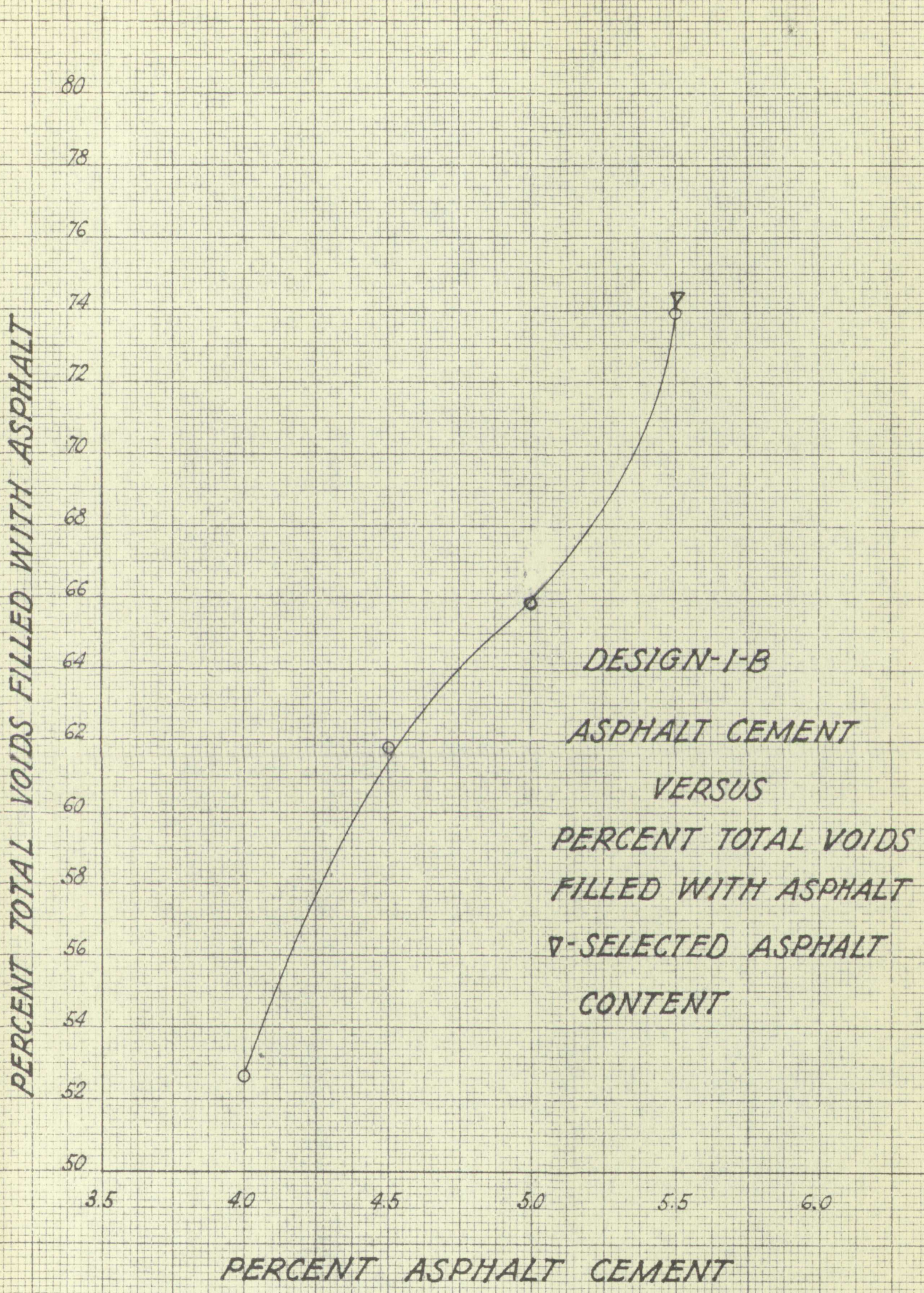

DESIGN-I-A
ASPHALT CEMENT
VERSUS
SOLID VOLUME DENSITY
∇-SELECTED ASPHALT
CONTENT
PERCENT SOLID VOLUME DENSITY
98
97
96
95
94
93
92
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT


98
96
94
92
DENSITY (%)
65
55
45
35
25
HVEEM STABILITY (%)
DESIGN-I-A
HVEEM-STABILITY
AND DENSITY
VERSUS
ASPHALT CONTENT
DOUBTFUL STABILITY
3.5
4.0
4.5
5.0
5.5
6.0
ASPHALT CEMENT (% BY WEIGHT)

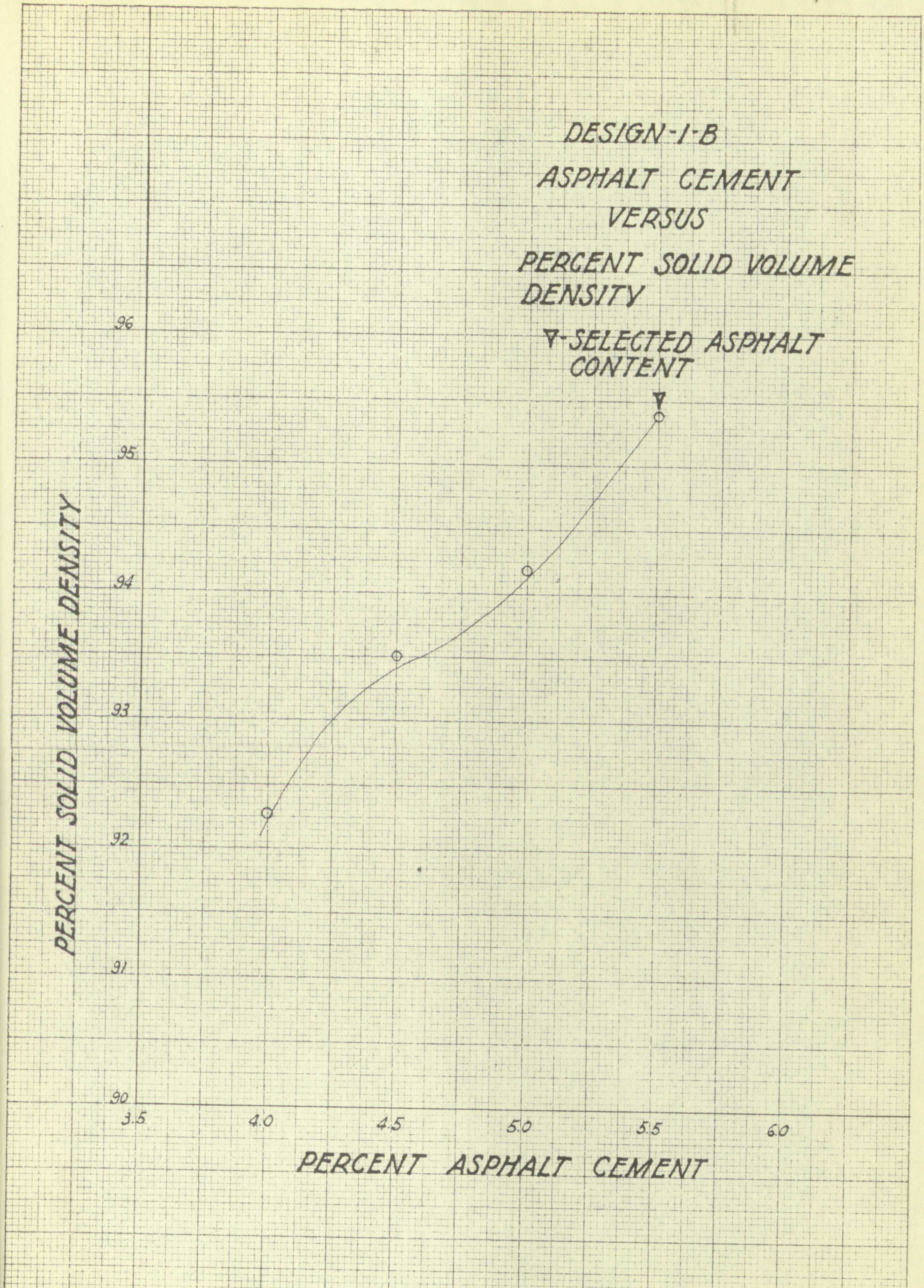

DESIGN-I-B
ASPHALT CEMENT
VERSUS
MARSHALL STABILITY
AT 140°F
▽-SELECTED ASPHALT
CONTENT.
MARSHALL STABILITY - POUNDS AT 140°F.
2800
2600
2400
2200
2000
1800
1600
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT

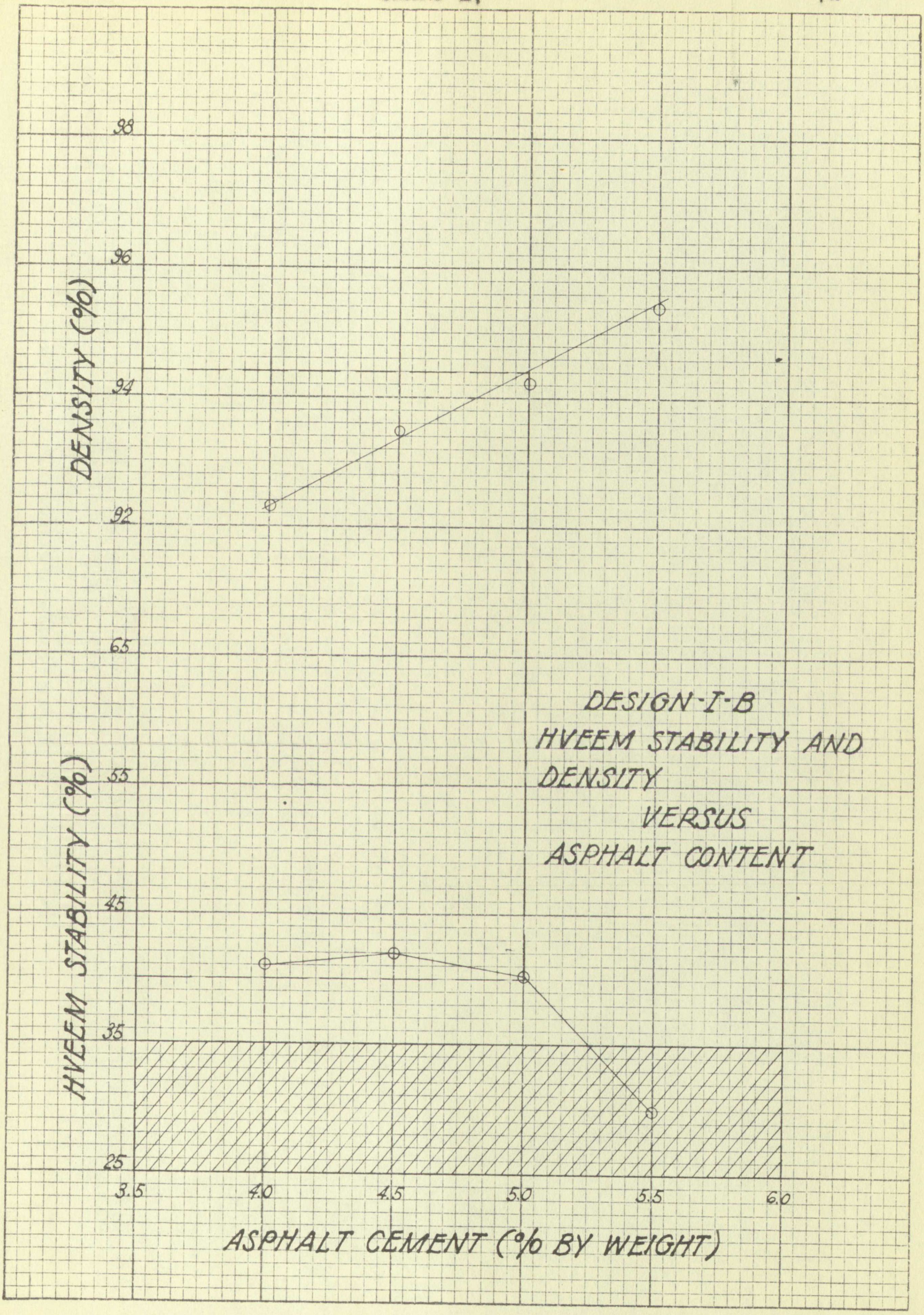

MAXIMUM
DESIGN-I-B
ASPHALT CEMENT
VERSUS
MARSHALL FLOW VALUE
IN 1/32 OF AN INCH
∇-SELECTED ASPHALT
CONTENT
MARSHALL FLOW VALUE IN 1/32 OF INCH
6
5
4
3
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT


144
143
142
141
140
WEIGHT PER CUBIC FOOT - POUNDS
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT
DESIGN-I-B
ASPHALT CEMENT
VERSUS
WEIGHT PER CUBIC
FOOT POUNDS-
∇-SELECTED ASPHALT
CONTENT.

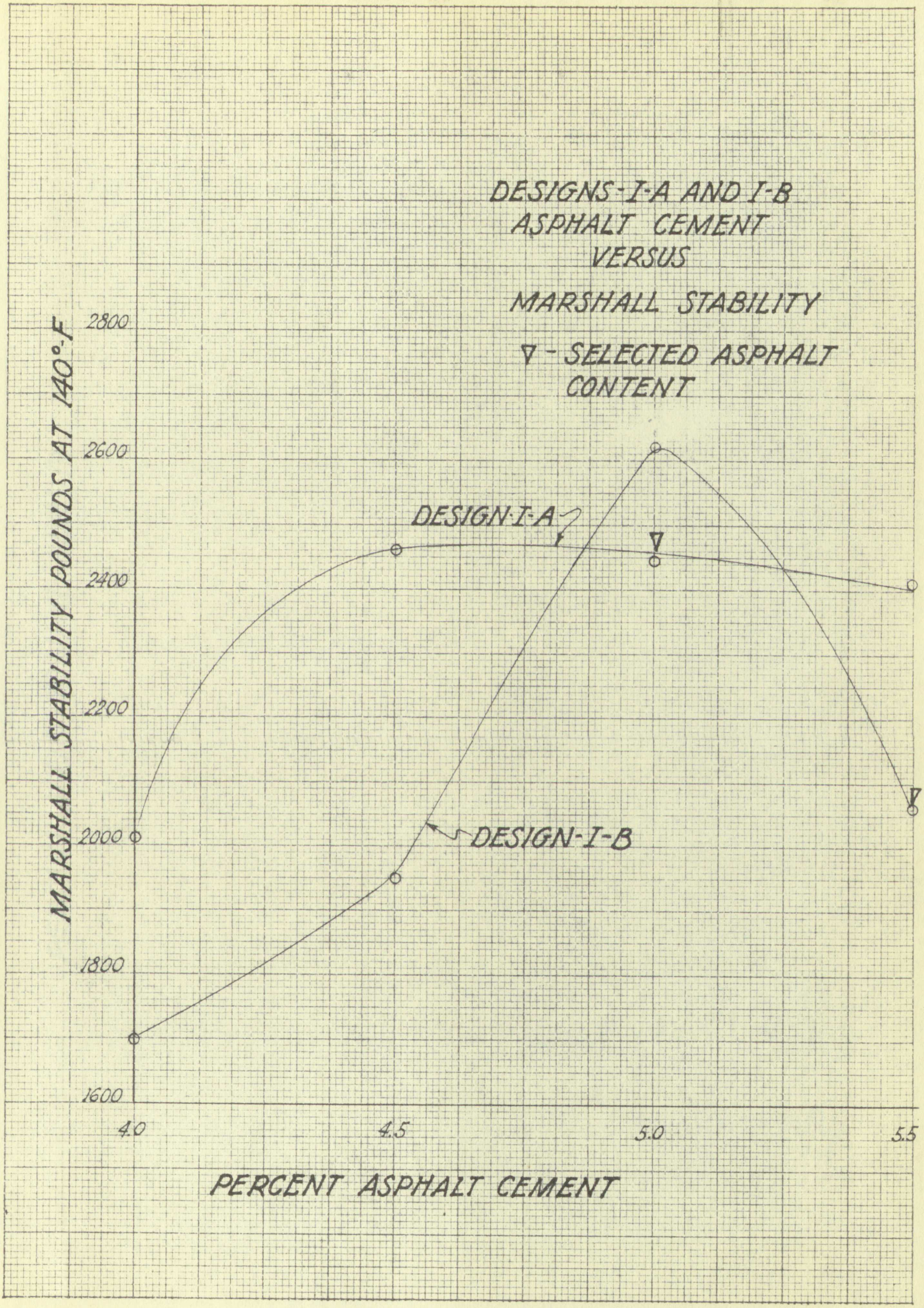


80
78
76
74
72
70
68
66
64
62
60
58
56
54
52
50
PERCENT TOTAL VOIDS FILLED WITH ASPHALT
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT
DESIGN-I-B
ASPHALT CEMENT
VERSUS
PERCENT TOTAL VOIDS
FILLED WITH ASPHALT
∇-SELECTED ASPHALT
CONTENT


DESIGN-I-B
ASPHALT CEMENT
VERSUS
PERCENT SOLID VOLUME DENSITY
∇-SELECTED ASPHALT CONTENT
PERCENT SOLID VOLUME DENSITY
96
95
94
93
92
91
90
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT



DESIGN-I-B
HVEEM STABILITY AND DENSITY VERSUS ASPHALT CONTENT
DENSITY (%)
98
96
94
92
HVEEM STABILITY (%)
65
55
45
35
25
3.5
4.0
4.5
5.0
5.5
6.0
ASPHALT CEMENT (% BY WEIGHT)


DESIGNS-I-A AND I-B
ASPHALT CEMENT
VERSUS
MARSHALL STABILITY
∇ - SELECTED ASPHALT CONTENT
MARSHALL STABILITY POUNDS AT 140°-F
2800
2600
2400
2200
2000
1800
1600
DESIGN-I-A
DESIGN-I-B
4.0
4.5
5.0
5.5
PERCENT ASPHALT CEMENT

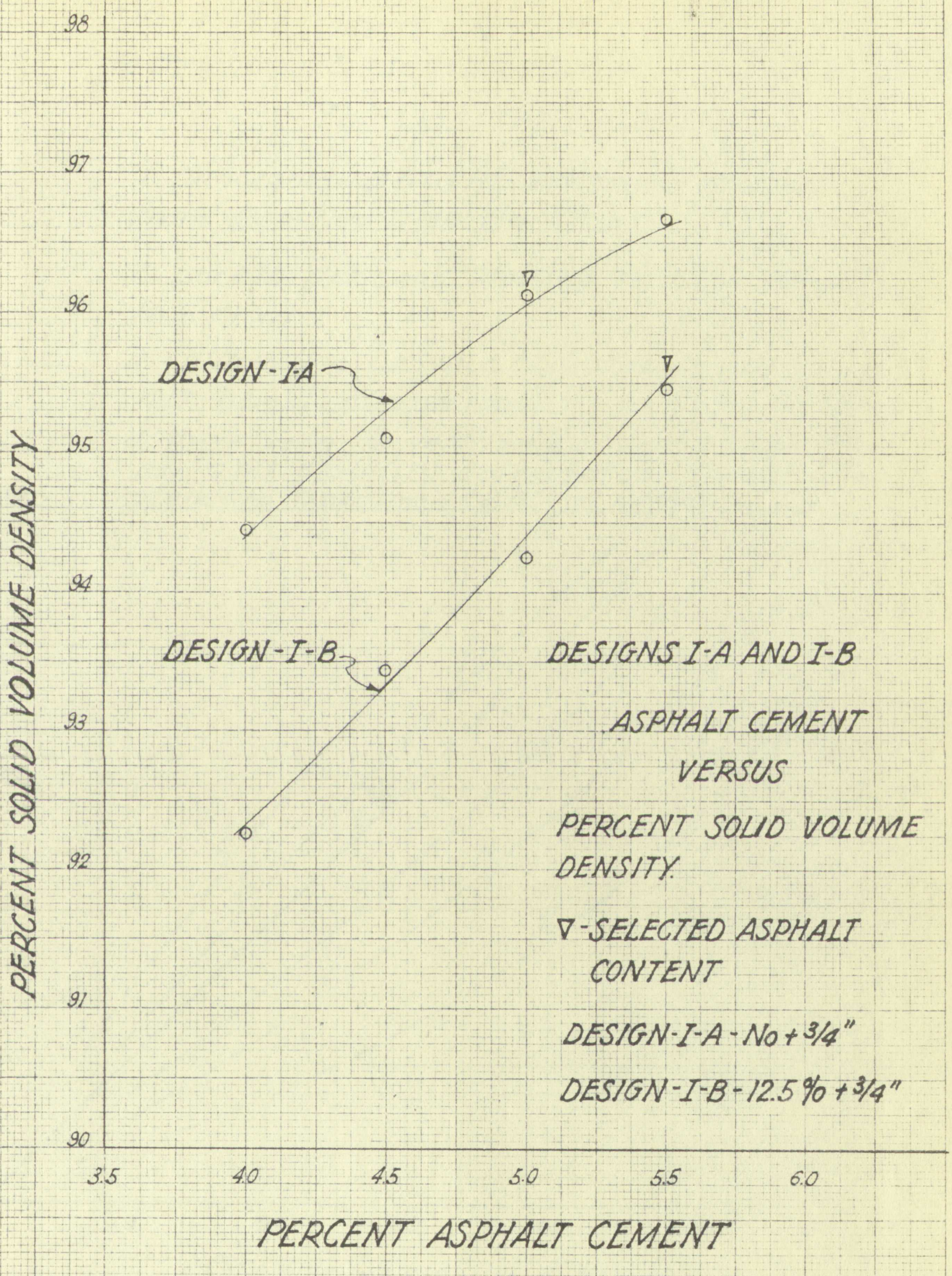
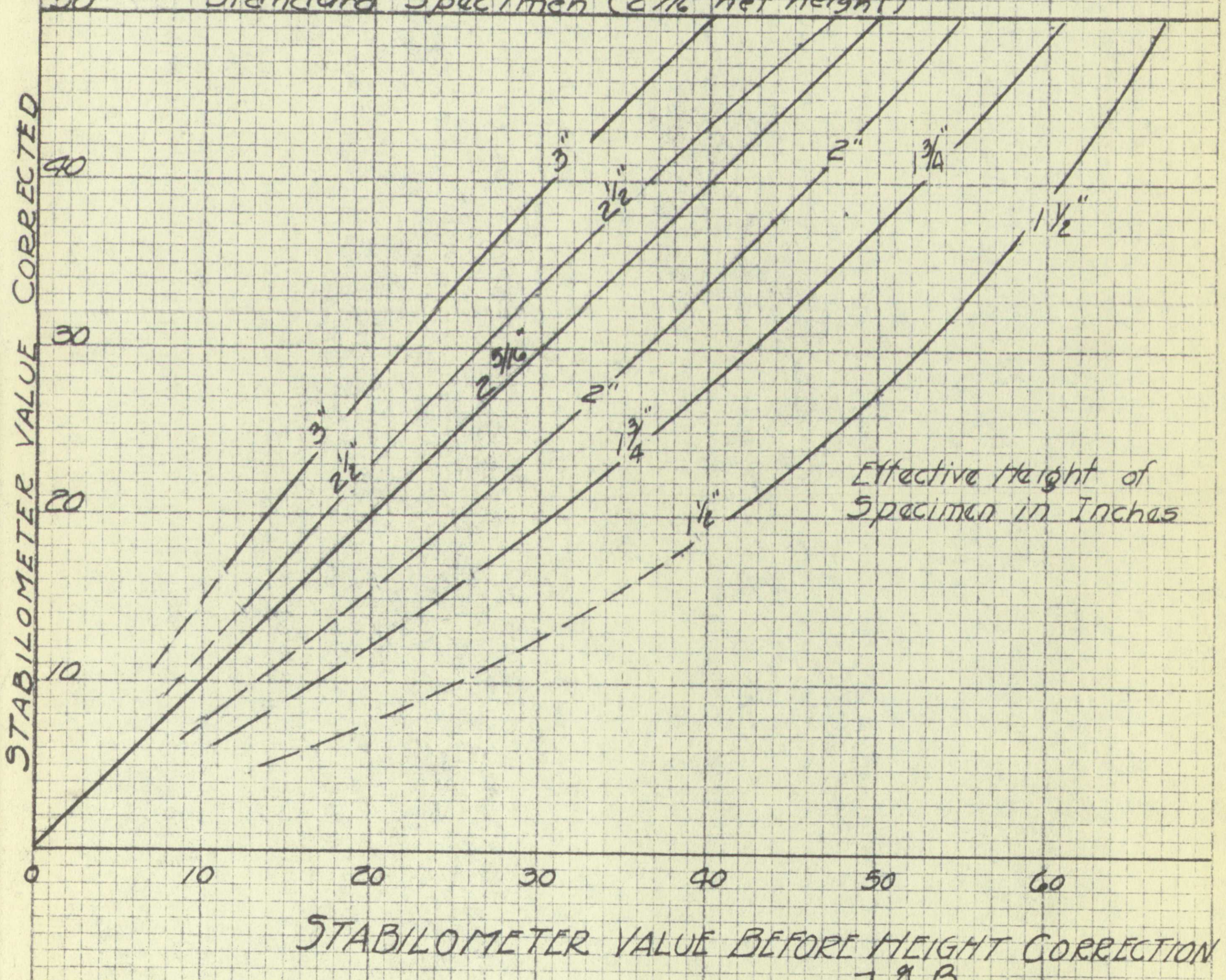

98
97
96
95
94
93
92
91
90
PERCENT SOLID VOLUME DENSITY
DESIGN-I-A
DESIGN-I-B
DESIGNS I-A AND I-B
ASPHALT CEMENT
VERSUS
PERCENT SOLID VOLUME
DENSITY
∇-SELECTED ASPHALT
CONTENT
DESIGN-I-A-No + 3/4"
DESIGN-I-B-12.5% + 3/4"
3.5
4.0
4.5
5.0
5.5
6.0
PERCENT ASPHALT CEMENT

CHART FOR CORRECTING HVEEM STABILOMETER VALUES TO STANDARD SPECIMEN HEIGHT OF $2\frac{5}{16}$" (NET)

TO USE THE CHART

1. Disregarding height, determine per cent stability from Relative Stability Chart.
2. Locate per cent stability on lower margin of this Chart.
3. Follow line upward to Curve representing actual net height of specimen.
4. Then refer to left margin which will indicate per cent stability corrected to the equivalent of a standard Specimen (2 5/16" net height)



J. G. Brown
5-10-49

CHAPTER IX

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations given in the following paragraphs are believed warranted on the basis of the information and data presented in this investigation.

Gradation of Aggregates. The density of a paving mixture is influenced by the grading of the material, the more uniform the grading the less voids in the mineral aggregate and therefore higher structural strength. A grading which allows 40% to 60% (by weight) passing the #4 sieve will in general give the best void ratio. If a finer grading is used there will not be enough voids for the asphalt to fill. A coarser grading will result in an open graded type. The open graded type is not covered in this investigation.

There is a difference of opinion as to the proper amount of minus #200 material to be used in the design of a Hot Plant Paving Mix. It is a proven fact that paving mixtures containing excess amounts of minus #200 material tend to crack with age. Surface water enters these cracks and the pavement soon deteriorates. The surface area of the minus #200 is large as compared to larger material. For example the surface area for minus #200 material is 250 square feet per pound, whereas for the minus #10 it is only

18 square feet per pound. To coat the large surface area of the minus #200 material properly a large amount of asphalt cement would be required. This would result in low stability of the pavement. The recommended amount of minus #200 material is no less than 5% to no more than 12%; above 12% should not be allowed in a Hot Plant mix pavement.

The present Marshall machine and procedure are applicable for conducting tests on paving mixtures containing aggregates of one inch maximum size or less. The designer of the Marshall machine is now working on a mold and other apparatus that will be capable of testing paving mixtures containing aggregates up to 2½ inch maximum size.

Asphalt Content. The amount of asphalt in a paving mixture affects the test properties more than any other constituent. A step by step discussion of the effect on the amount of asphalt on the different test properties was taken up in Chapter VIII, and illustrated by curves. It was shown in Chapter VIII that the asphalt content was the most critical variable in a paving mixture. If too small amount of asphalt is used, the pavement is dry and brittle, has low stability, a large per cent of voids, and the weight per cubic foot is low. If a large amount of asphalt is used the pavement is plastic and unstable and tends to heave or shove, the stability is low and, as a general rule, the weight per cubic foot is on the low side.

18 square feet per pound. [illegible]
of the minus No. 40 material [illegible]
cement would be [illegible]
of the pavement. The recommendations [illegible]
material [illegible]
should not be [illegible]

The present [illegible]
able for [illegible]
gregates of [illegible]
of the [illegible]
apparatus [illegible]
containing [illegible]

[illegible] Content. [illegible]
mixture [illegible]
constituent.) [illegible]
the amount of asphalt [illegible]
was [illegible]
It was shown in [illegible]
the most critical [illegible]
small amount of asphalt is used [illegible]
brittle, [illegible]
and the [illegible]
of asphalt is [illegible]
and tends to [illegible]
a general rule, [illegible]

It is very important to determine the "optimum asphalt," so that the design criteria are satisfied. The only satisfactory way that has been found to determine the proper amount of asphalt content is by comparing the different test properties using different percentages of asphalt cement and correlating the results with pavements that are giving good service.

Voids in Paving Mixture Filled with Asphalt. The asphalt-void ratio in a paving mixture is the ratio of the volume of asphalt in the mix to the voids in the aggregate. For example in Design I-A, asphalt content 5%, the aggregates occupy 84.71% of the volume of the test specimen; therefore, there is 15.27% voids which theoretically can be filled with asphalt, 11.44% of the 15.27% voids were filled with asphalt, or 74.91%. In other words, 75% of the voids in the aggregate were filled with asphalt. There remained in the mixture 3.87% voids. This item may not seem to be important in the design of a paving mixture, but this one item has caused a lot of trouble in the past because if enough voids are not left in the mixture at the time it is laid to take care of additional compaction under heavy traffic, the result will be the same as that of a mixture containing too much asphalt, and the pavement will bleed and shove. In other words, sufficient volume should be allowed in the mat for additional compaction due to traffic.

It is very important [illegible] phalt,' as [illegible] the design [illegible] only satisfactory [illegible] proper amount of asphalt [illegible] ferent [illegible] cement and [illegible] giving [illegible]

Voids in [illegible]

asphalt-[illegible] volume of [illegible] For example [illegible] gates occupy [illegible] the volume of [illegible] Therefore, there is [illegible] be filled with asphalt [illegible] filled with [illegible] voids in the [illegible] mained in the [illegible] to be important in the design [illegible] one item [illegible] if enough [illegible] it is [illegible] traffic, the [illegible] containing [illegible] and above. [illegible] allowed in [illegible]

The recommended percentage of voids filled with asphalt cement is 75% of the voids in the mineral aggregate.

Density. The laboratory density which was obtained by using 55 blows of the hammer on each face of the specimen checked very close to the density obtained in the field on the Tucumcari project. The per cent solid volume density of field cores taken from the pavement after it had been rolled with pneumatic rollers, 10 ton three-wheeled rollers, and tandem rollers was 95%, whereas that of the laboratory specimens were 96.13%.

At the end of six months' use another series of cores were taken from the pavement and tested. These specimens showed 96.5% of solid volume density due to heavy traffic on the pavement. From the above observation it is recommended that the per cent voids in the total mix should not be less than 3% nor more than 5%.

Plant Control. The old saying "that a chain is only as strong as its weakest link" is very true of the construction of Hot Plant Mix Pavement. A pavement may be properly designed and the specifications carefully written, but if accurate plant control is not maintained an inferior product will result. This is especially true if the mix is produced by a continuous mix plant that utilizes volumetric control for both the aggregates and bituminous materials. Unless the job formula is closely adhered to and all

The recommended [illegible] filling with asphalt

cement is 75 [illegible]

Density. The [illegible]

by using 75 blows of the [illegible]

men checked very closely the density [illegible]

on the [illegible]

of field-cored [illegible] from the [illegible]

rolled with [illegible]

and tandem rollers was 9[illegible]

specimens were 9[illegible].

At the end of [illegible]

cores were taken [illegible]

mens showed 9[illegible]

traffic on the pavement [illegible]

recommends that the [illegible]

not be less than 9[illegible]

Plant Control. [illegible]

as strong as its weakest [illegible]

struction of the plant [illegible]

properly designed and [illegible]

but if accurate [illegible]

product will result. [illegible]

is produced by a continuous [illegible]

metric control [illegible]

lin. Unless the [illegible]

tolerances closely checked, serious non-uniformities will result. In the case of a plant using weight control, the same rigid inspection should be maintained, but errors are more easily caught in this type of plant than in a continuous mix plant.

It is recommended on all hot mix jobs that a complete field laboratory be established and fully equipped, the equipment to include a Marshall stability machine and a centrifuge extractor.

Cores should be taken from the pavement after the Lay Down machine has laid the pavement and also after rolling has been completed. One specimen should be taken for every 500 feet of pavement. The following are a few recommended tolerances that should be used in the control of the job:

Passing No. 4 and for larger sieves	Plus or minus 5%
Passing No. 10 to No. 40 inclusive	Plus or minus 4%
Passing No. 80 sieve	Plus or minus 3%
Passing No. 200 sieve	Plus or minus 2%

Asphalt Cement

Designation	Temperature average	Min.	Max.
120-150, 150-200, 200-300	250-275	225	325

The author of this thesis has recently revised and rewritten the Standard Specifications for Hot Plant Mix Pavements for the New Mexico State Highway Department, and

tolerances closer [illegible]

result. In [illegible]

same rigid ing, [illegible]

more easily [illegible]

tinuous [illegible]

It is recommended [illegible]

field laboratory be [illegible]

equipment to [illegible]

centrifuge extraction.

Core [illegible]

Lay-Down [illegible]

has been [illegible]

500 feet of pavement. [illegible]

tolerances [illegible]

Passing No. 4 and [illegible]

Passing No. 40 [illegible]

Passing No. 80 [illegible]

Passing No. 200 [illegible]

[illegible]

Designation [illegible]

120-150, 150-[illegible]

The [illegible]

rendition the [illegible]

Pavements for the [illegible]

has incorporated many important changes that were brought to light by the research on which this thesis is based. It is believed that the contents of this thesis will be of practical value to the practicing engineer who is interested in Bituminous Pavement Construction.

has incorporated [illegible] [illegible] [illegible] [illegible]

to light by the [illegible] [illegible] [illegible] [illegible]

It is believed [illegible] [illegible] [illegible] [illegible]

practical value [illegible] [illegible] [illegible] [illegible]

in bituminous [illegible] [illegible]

BIBLIOGRAPHY

BIBLIOGRAPHY

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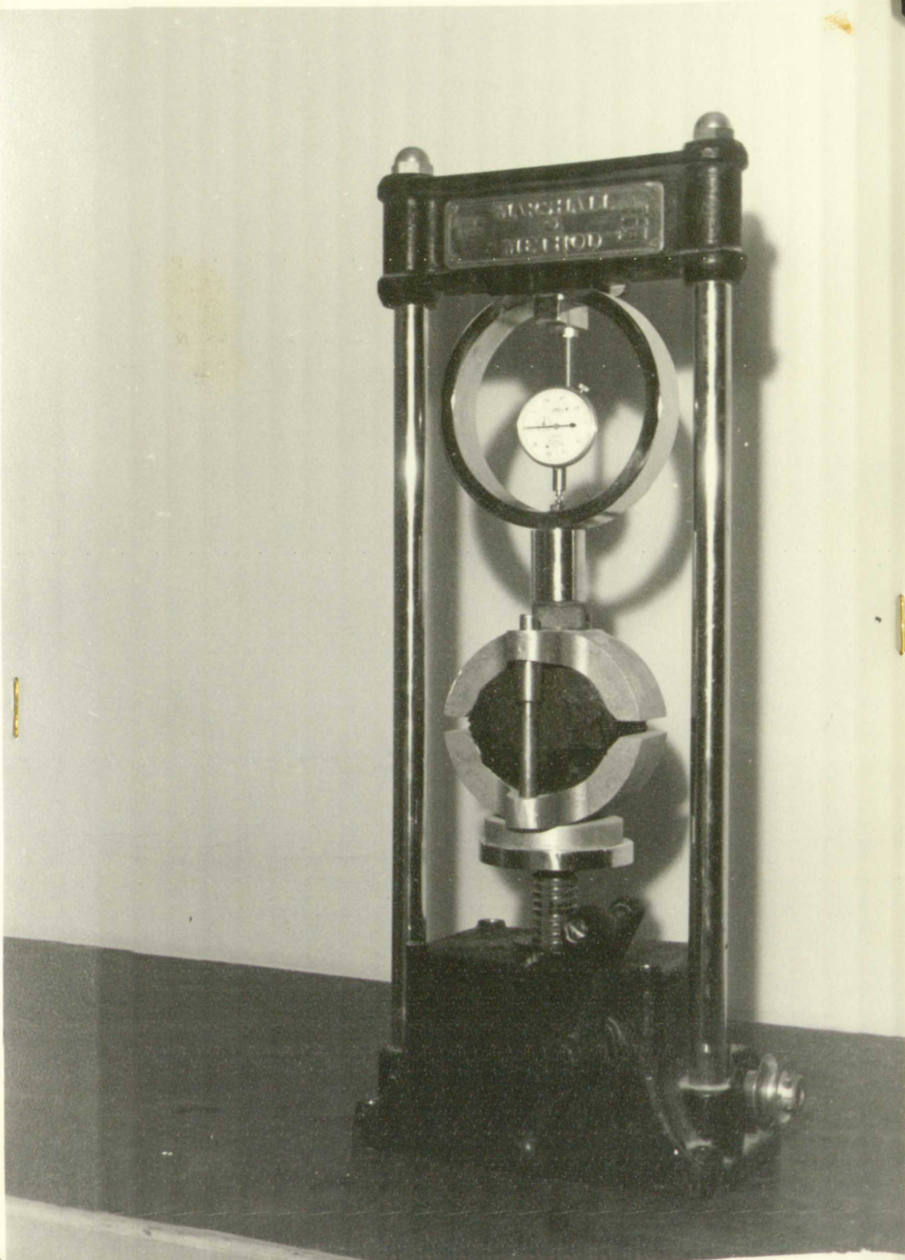
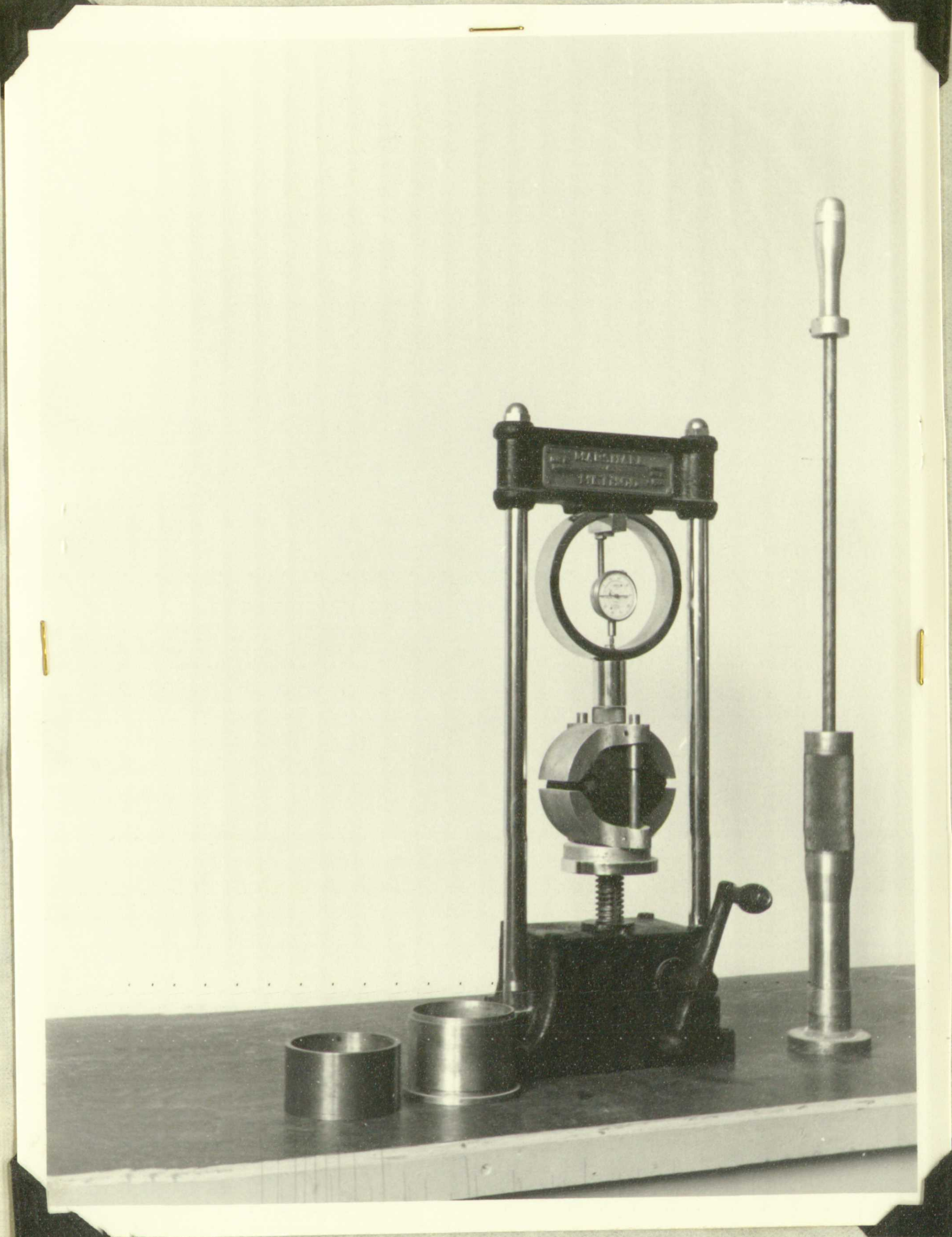
"Design of Asphaltic Concrete Paving Mixtures." Construction Bulletin C-14. Texas Highway Department, October, 1947.

APPENDIX

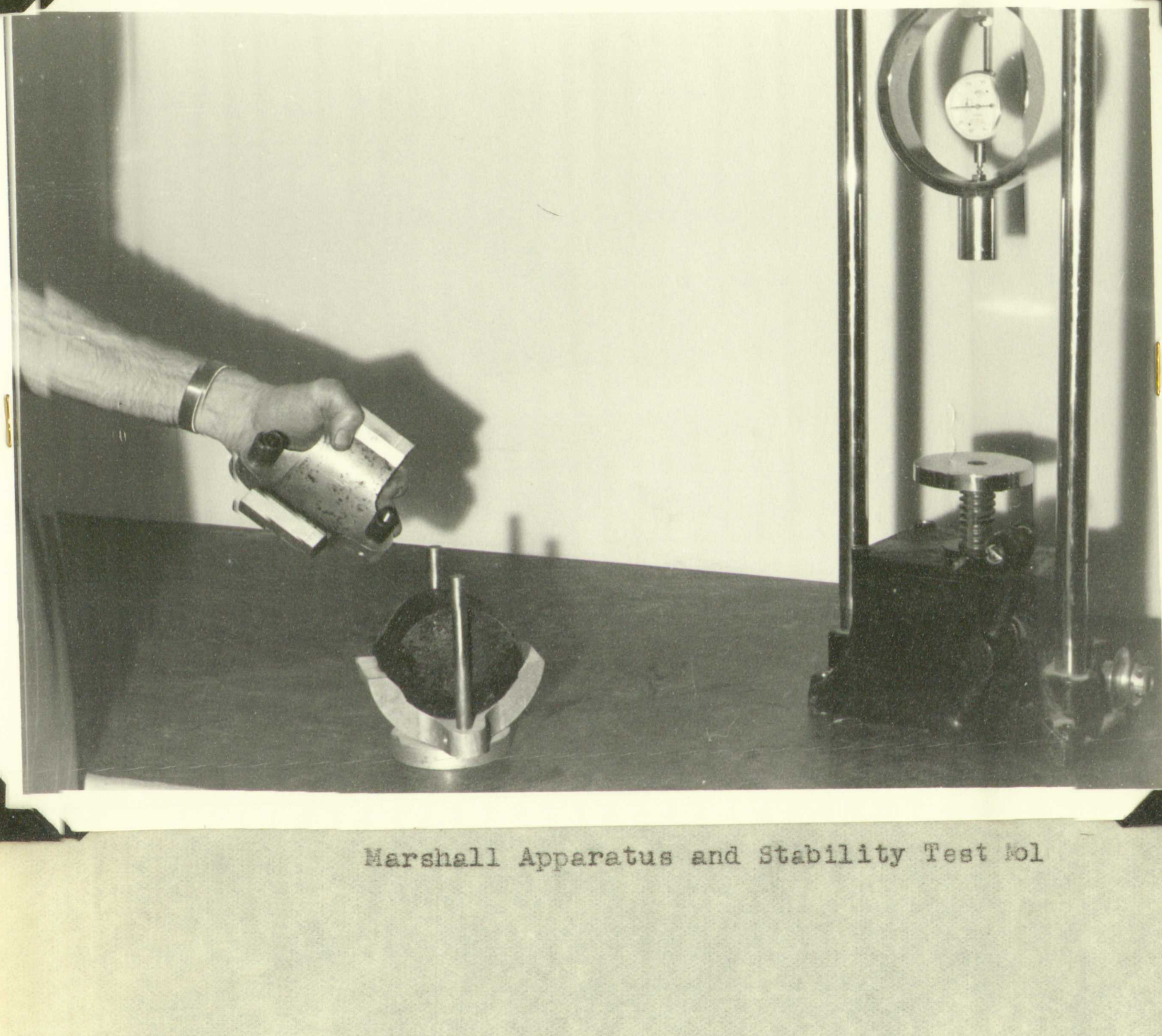
Sieves Used in Gradation Tests



Marshall Apparatus and Test Specimen



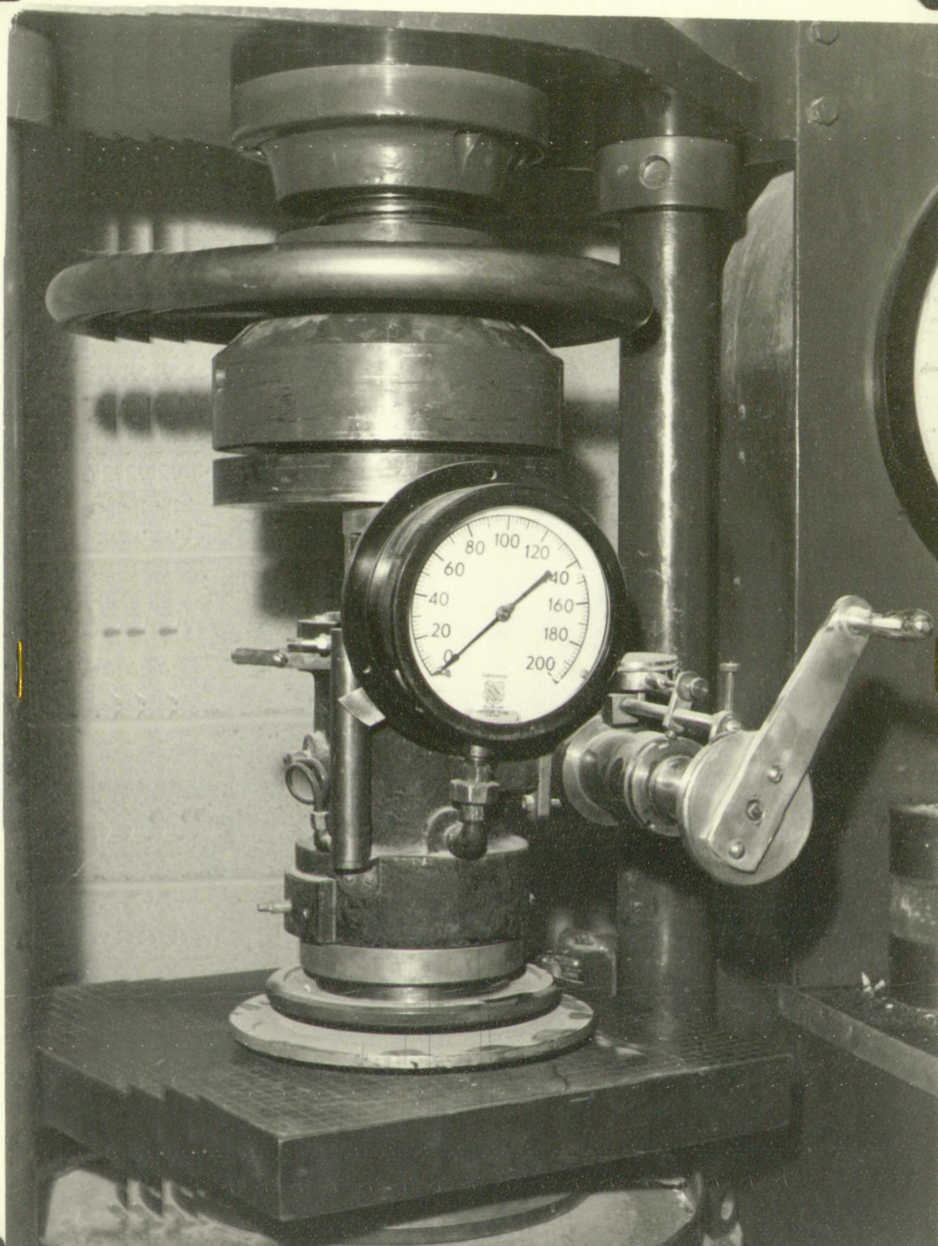
Marshall Apparatus, Compaction Hammer and Molds



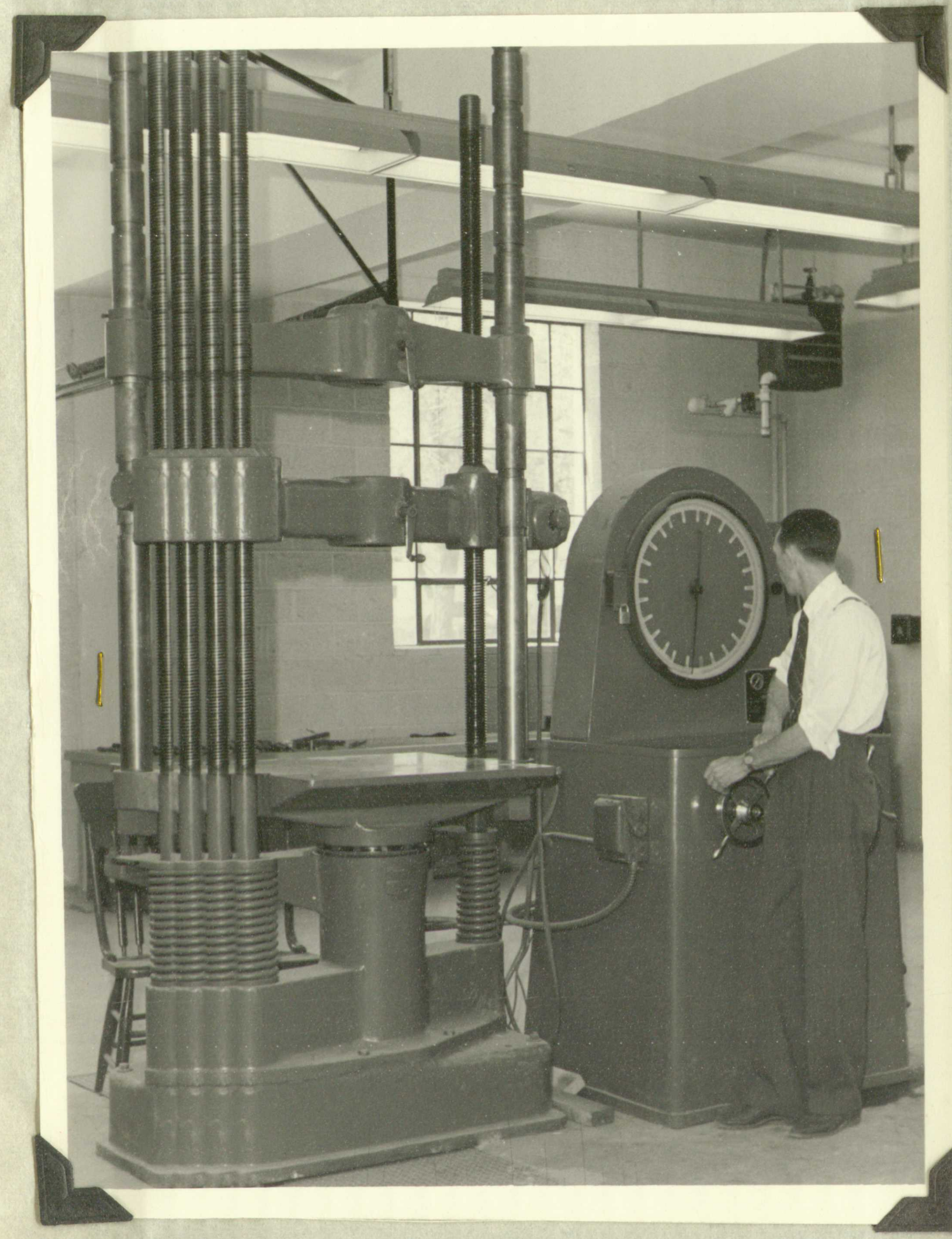
Marshall Apparatus and Stability Test Mol

Hvveem Stabillometer and Compression Machine

Hveem Stabilometer--Unassembled

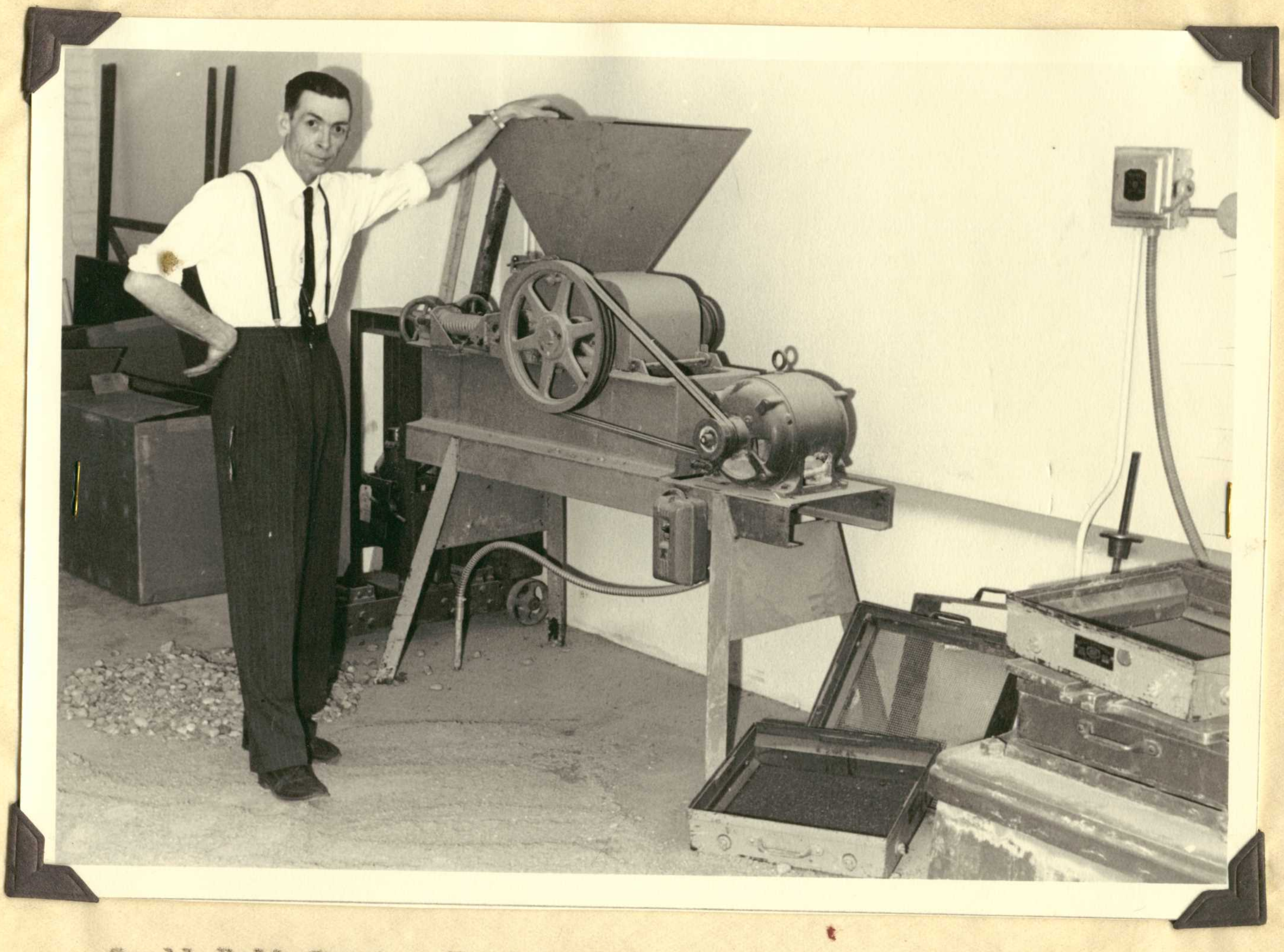


Hveem Stabilometer in Testing Position



Twenty-four Thousand (24,000) Pound Testing Machine
Used in Connection With Hveem Stabilometer

Centrifuge Machine for Extracting Bituminous
Materials from Roadway Specimens



Small Roll Crusher Used to Reduce Pit Run Aggregate to Proper Size for Use in Specimens

D.T.

IMPORTANT!

Special care should be taken to prevent loss or damage of this volume. If lost or damaged, it must be paid for at the current rate of typing.