STIFFNESS OF ASPHALT CEMENTS EVALUATED BY COMPRESSION

by

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Study Number 2-8-59-9
Research Area 8

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STIFFNESS OF ASPHALT CEMENTS
EVALUATED BY COMPRESSION

I. OBJECTIVES OF STUDY NO. 2-8-59-9, RESEARCH AREA 8

Objectives of the Study are to:

(1) Investigate the asphalt cements used by the Texas Highway Department,

(2) Establish specifications to assure the use of superior asphalts by the Department, and

(3) Determine how the durability of asphalt cements in service can be improved.

This report describes preliminary development of a procedure for evaluating the rheological and mechanical properties of asphalt cements at low atmospheric temperatures. The research applied to the three objectives listed above.

II. HISTORY

Study No. 2-8-59-9, Research Area 8, was started February 1, 1959, as Research Project No. 15.

During the past nine years studies concerning the viscosities of asphalt cements used by the Texas Highway Department have been conducted over the temperature range of 50-275°F (10-135°C). This work has resulted in the substitution of viscosities for penetration values in THD purchase specifications.

However, it has been realized for a long time that the rheological (flow) and mechanical properties of such asphalts at temperatures below 50°F are also extremely important to the serviceability of a pavement and that a method or methods should be developed for measuring these properties. It is our belief that the types of viscometers used to determine viscosities of asphalt cements below 50°F do not provide sufficiently accurate and informative values.

It was conceived that a properly controlled compression test could give information on the behaviors of various asphalts over a useful range of low atmospheric temperatures.

The investigations discussed below were made during the period October 1967 - May 1968.

This is the final report of Study No. 2-8-59-9.

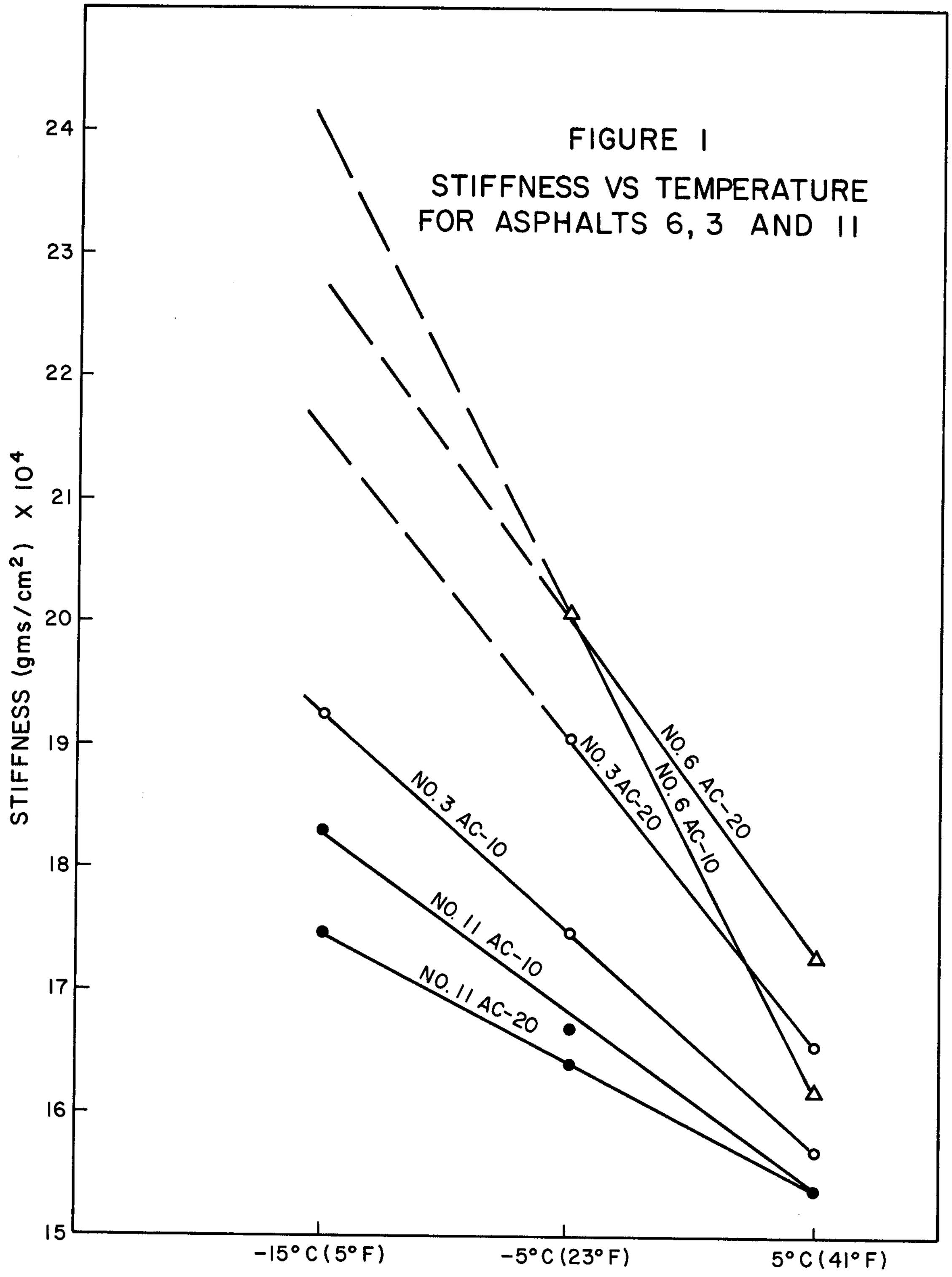


FIGURE 1
STIFFNESS VS TEMPERATURE
FOR ASPHALTS 6, 3 AND 11
STIFFNESS (gms/cm²) X 10⁴
24
23
22
21
20
19
18
17
16
15
-15° C (5° F)
-5° C (23° F)
5° C (41° F)
NO. 6 AC-20
NO. 6 AC-10
NO. 3 AC-20
NO. 3 AC-10
NO. 11 AC-10
NO. 11 AC-20

III CONCLUSIONS

1. From the exploratory determinations of stiffness, conducted over the temperature 5° to -15°C (41° to 5°F), it is concluded that the compression test described in this report will be useful for evaluating the rheological properties of asphalt cements at low atmospheric temperatures. It is possible that, for certain asphalts, the test temperature can be extended to -25°C (-13°F) or lower.

2. The data can be used to compare the stiffness of different asphalts and different grades of each asphalt at a constant rate of strain. Also, the data indicate the temperature susceptibility of each kind and grade of asphalt at the low temperatures.

3. Data for each kind and grade of asphalt investigated are given in Table 1, page 7. Plots of these data are shown in Figure I, facing. By reference to this figure it is seen that Asphalts 6, 3 and 11 possess decreasing stiffness at low temperatures in the order named. This order is the same as for viscosities at 59°F, shown in Table 2, page 11.

Asphalt No. 6, AC-10 is more susceptible to temperature change than is No. 6 grade AC-20. The stiffness curves for the 2 grades of Asphalt No. 6 cross at -5°C (23°F) and a stiffness of 20 x 10^4 gm/cm^2.

Asphalt No. 11, AC-10 grade at the low temperatures shown on Figure I is more susceptible to temperature change than is No. 11, AC-20 grade. The stiffness curves for the 2 grades of Asphalt No. 11 cross at 5°C (41°F) and a stiffness of 15.5 x 10^4 gms/cm^2.

The plots of Asphalt No. 3 show it to have a stiffness intermediate to Asphalts Nos. 6 and 11. Grade AC-20 of Asphalt No. 3 is stiffer at the low temperatures shown than is the AC-10 grade. An extension of the plots for Asphalt No. 3 indicate that the curves cross at approximately 30°C (86°F) and a stiffness of 13x10^4 gms/cm^2.

The following tabulation consolidates these values.

Asphalt	Stiffness lines for AC-10 and AC-20 cross at	
	Temperature °C (°F)	Stiffness gms/cm^2
No. 6	-5° (23°)	20.0
No. 11	5° (41°)	15.5
No. 3	30° (86°) (Extrapolated)	13.0

Thus, it is obvious that the processing, as well as the source of an asphalt, influences the rheological properties of asphalt cements at low temperatures.

4. It is important to the road builder that at low temperatures the AC-10 grade may, in some cases, be stiffer than the supposedly harder AC-20 grade from the same supplier. This reversal is caused by the greater temperature susceptibility of the AC-10 materials.

5. The differences in stiffness of the 6 asphalts found by this investigation should lead to an explanation of certain losses in serviceability experienced in bituminous pavement subjected to heavy traffic at low atmospheric temperatures.

Table 1

Values for Stiffness of Asphalt Cements Studied

Asphalt No.	Grade	Temperature °C	Temperature °F	Stiffness gms/cm^2
3	AC-10	5	41	157,200
3	AC-10	-5	23	175,100
3	AC-10	-15	5	192,500
3	AC-20	5	41	165,500
3	AC-20	-5	23	190,700
3	AC-20	-15	5	183,100
6	AC-10	5	41	162,200
6	AC-10	-5	23	210,000
6	AC-10	-15	5	186,000
6	AC-20	5	41	173,700
6	AC-20	-5	23	203,700
6	AC-20	-15	5	206,300
11	AC-10	5	41	160,750
11	Ac-10	-5	23	167,700
11	AC-10	-15	5	185,000
11	AC-20	5	41	157,300
11	AC-20	-5	23	161,600
11	AC-20	-15	5	177,500

IV. DISCUSSION

These exploratory studies of a compression method for evaluating the rheological properties of asphalt cements at temperatures from 5°C (41°F) to -15°C (5°F) appear to offer considerable promise. However, there are several problems that face the investigator. Some of these have been encountered and solved during the investigation covered by this report.

(a) It is necessary to bring the asphalt sample to the desired temperature as soon as possible after casting in the mold. Further, this temperature must be maintained constant throughout the testing procedure.

(b) Timing of the sample preparation and its testing must be established and maintained. This is a must in all viscosity measurements at temperatures below the softening point of the material. The problem is caused by the development of structure within the asphalt which is commonly known as age-hardening. Ignoring this phenomenon has been responsible for much of the "poor" data obtained on asphalts. Thus, in these experiments a rather tight time schedule was maintained.

(c) Molding of the sample presents a problem, which has not been completely solved. The method used did not always create a sufficiently smooth top surface for the sample. At 41° and 23°F satisfactory data were obtained but at 5°F troubles were encountered with the stiffer asphalts. The irregularities in the sample surface may amount to only a few microns, but this can result if the force is not being applied to the entire surface area. This problem is illustrated by the data obtained at 5°F on the AC-10 and AC-20 samples of Asphalt No. 6 and on the AC-20 sample of Asphalt No. 3.

V. RECOMMENDATIONS

No recommendations are made.

VI. FUTURE WORK

1.. Asphalt stiffness at different constant rates of strain should be correlated with asphaltic fracture resistance in order to determine the usefulness of the more easily obtained stiffness as a measure of material serviceability. The stiffnesses could be measured essentially as described in this report. The asphalt fracture resistance should be assessed by subjecting asphalt samples to realistic (in-service type) loading conditions at low temperatures.

2. Since asphaltic concrete fails in tension it should be more valuable to measure the asphalt itself in tension instead of compression.

3. The following data should be obtained: stiffnesses versus strain rate and temperature; strength versus displacement and strain rate for each temperature; total required energy (work) to fracture each specimen type at each test temperature and impulse.

4. From such a test program, a correlation should result between asphaltic stiffnesses at low temperatures and the tendency of the mixture to fracture when subjected to traffic loads at low temperatures. If the correspondence is good then measurements of asphalt stiffness can be readily employed to determine serviceability.

Table 2

Properties of Asphalt Cements Investigated

1967 Production

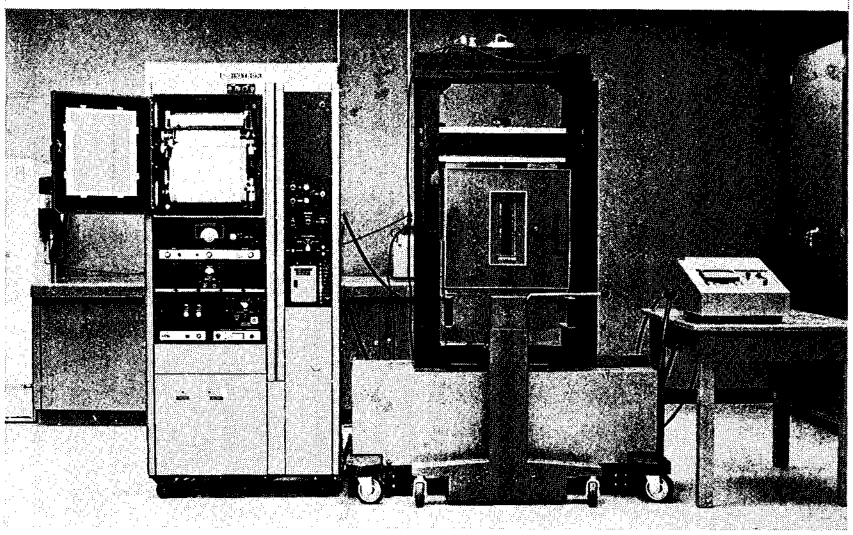
Asphalt No.	Grade	Penetration 77°/100gm/5 sec.	Viscosities, megapoises at			Viscosities, stokes, at	
			59°F	77°F	95°F	140°F	275°F
6	AC-10	84.0	11.7	0.70	0.080	1265	2.65
6	AC-20	50.5	32.0	2.10	0.185	2735	3.85
3	AC-10	85.5	7.8	0.83	0.085	1455	3.70
3	AC-20	70.0	15.0	2.10	0.290	2935	5.10
11	AC-10	91.5	7.3	1.45	0.175	1690	3.05
11	AC-20	58.5	12.4	2.15	0.410	3265	3.90

VII. EXPERIMENTAL WORK

1. Asphalts Investigated

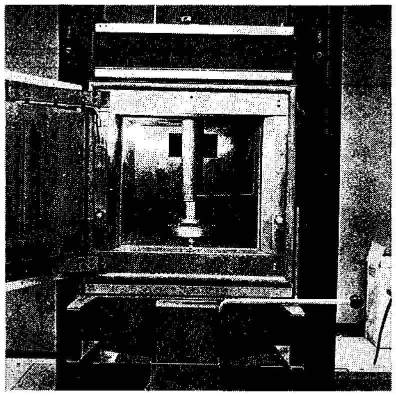
AC-10 and AC-20 grades of the 1967 production from three suppliers were studied. The asphalts were manufactured by suppliers Number 3, 6, and 11 who have sold asphalt paving cements to the Texas Highway Department for many years.

Standard rheological data on the 6 asphalts mentioned in this report are shown in Table 2, facing.



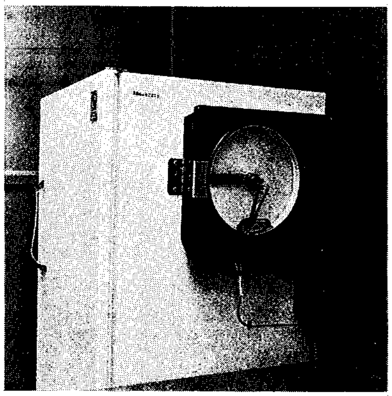
INSTRON TESTER, ENVIRONMENTAL
CABINET & TEMPERATURE CONTROL

a



INTERIOR OF
CABINET

b



CONTROLLED
REFRIGERATOR

c

FIGURE II

2. Test Equipment

An excellent Instron Tester (Model TTD1454) was available but a suitable Environmental Cabinet had to be purchased in order to maintain the samples at the desired temperatures during the testing procedure. In this cabinet low temperatures can be automatically attained and maintained at ±1°F, by either liquid nitrogen or liquid carbon dioxide. The latter cooling agent was used. It was also necessary to equip a General Electric refrigerator with controls to maintain a selected constant temperature. This cold box was required to maintain the test sample at the test temperature for a fixed period of time prior to transfer to the environmental unit in the Instron. A small air oven was used for softening the asphalt prior to casting the pancake shaped sample.

Figure II-a, facing, is a photograph of the Instron apparatus, environmental cabinet and automatic temperature controller. A view of the interior of the environmental cabinet with an asphalt sample in place is given in Figure II-b. The refrigerator and temperature recorder are shown in Figure II-c.

3. Selection of Sample Dimensions

A considerable amount of effort was expended in determining the most suitable sample dimensions. In work conducted a number of years ago it was found that a flat (pancake) sample should be used. A height even approaching the diameter of the disc is not satisfactory because the column will tend to bend under compression.

Preliminary tests were made using discs of asphalt with diameters ranging from 2.0 to 6.0 centimeters and thicknesses from 0.3 to 1.2 centimeters. Dimensions of the sample were found to affect ease of casting, smoothness of the disc, time required to cool to the desired low temperature and accuracy of the test measurement. For example, the larger samples required too long to cool and the small samples were difficult to handle.

A disc 4.0 centimeters in diameter and 0.6 centimeters thick was selected as the most suitable in all respects.

4. Selection of Temperature Range and Control

The following temperatures were used in preliminary tests

59°F	(15°C)
41°F	(5°C)
23°F	(-5°C)
5°F	(-15°C)

It will be noted that starting with 15°C each succeeding temperature drops by 10°C. Also, each temperature represents a whole degree of Centigrade and Fahrenheit. Consideration was given to testing at intervals of 5°C, but it was decided, for this exploratory work, to use the larger intervals so that changes caused by temperature would be more readily discerned. The studies indicated that at 59°F (15°C) the AC-10 and AC-20 asphalts were too soft to handle satisfactorily in the compression test because a definite change occurred in the geometry of the sample under the load that was applied. Omission of the 59°F test is of little importance because our interest is in lower temperature where the asphalt is much harder.

After a sample had been poured and had reached about 77°F, it and the mold were placed in the temperature controlled refrigerator which was maintained at the desired test temperature and finally the sample was moved to the Instron Environmental Cabinet maintained at the same temperature as the refrigerator.

Temperatures much below 5°F could not be attained in our regulated refrigerator. The Environmental Cabinet attached to the Instron can go to -100°F.

5. <u>Establishment of Time Sequence for Preparation and Testing of Each Sample</u>.

Long experience in the evaluation of asphalt has shown the absolute necessity for a fairly precise timing sequence in determining penetrations, viscosities, etc. After the molten asphalt has cooled to about room temperature (77°F), age or steric hardening starts to appear in the sample. Age hardening is the result of some type of structure formation and is dependent to a considerable extent on the source and processing of the asphalt. The phenomenon is time dependent -- it proceeds rapidly during the first few hours after the sample becomes quite viscous and then gradually slows down. It is imperative that testing should be done as soon as practical after the sample has attained the desired temperature. For this reason the following time schedule was established and adhered to in the experiments described in this report. The sequence is as follows:

<u>30 minutes</u> -- used to pour, form and cool the sample to room temperature. At the end of this time the filled mold is placed in the temperature controlled refrigerator.

<u>60 minutes</u> -- are allowed in the cold box to attain the desired temperature throughout the sample.

<u>5 minutes</u> -- are used to remove sample from the mold, remove silicone grease from edges of the sample and wrap the sample with three layers of 3M Scotch Filament Tape, Pressure Sensitive 880.

<u>15 minutes</u> -- in the refrigerator to reestablish the desired temperature.

<u>5 minutes</u> -- in Instron Cabinet before starting test.

Thus 105 minutes elapse between pouring the hot asphalt and start of the compression test on the sample at the desired test temperature. All samples are cooled for the same length of time independent of asphalt source, grade or the temperature used.

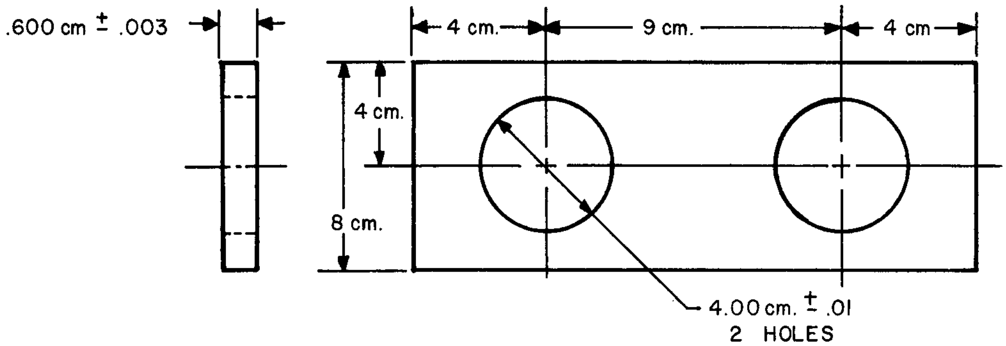
6. Establishment of Suitable Loading Range

The Instron Recorder plots time or deformation versus load. At low loads the plot is a curved line but after about 30 to 40 pounds of load has been applied a straight line appears. Slight irregularities in the surface of the sample must be eliminated in order to obtain a straight line. The low values obtained for Asphalt No. 6 (for both AC-10 and AC-20 grades) and Asphalt No. 3 AC-20 grade all at -15°C (5°F) were probably caused by the 200-pound load not providing a completely smooth surface.

7. Necessity for Confining the Sample

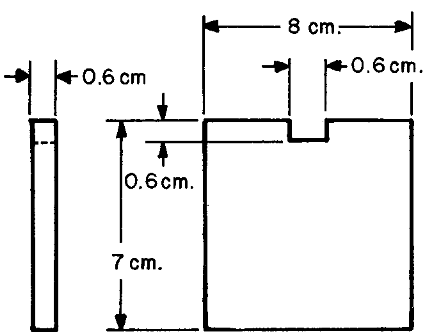
Since the purpose of this study was primarily to evaluate the asphaltic binder in a hot-mix pavement, the asphalt under test should be confined because that is its condition in the pavement. Some tests were run nevertheless on unconfined discs and it was found that samples as warm as 41°F were badly deformed during compression under a load of 200 pounds. At lower temperatures the samples would frequently break at the edges.

To prevent change in dimensions of the cold sample, after it was removed from the mold, the circumference was wrapped with three layers of 3M Scotch Brand Filament Tape cut to the thickness of the sample (0.6 cm).

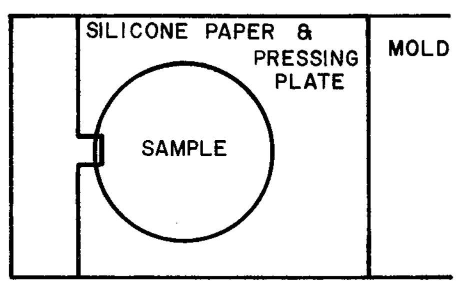


(a)

MOLD TO BE MADE OUT OF ALUMINUM AND ALL SURFACES MUST BE SMOOTH. THE INSIDE SURFACE OF THE HOLES MUST BE VERY SMOOTH SO THE COLD TEST SAMPLE WILL SLIP OUT EASILY.



(b)



(c)

NOT TO SCALE

DIMENSIONS OF MOLD AND PRESSING PLATE

FIGURE III

8. Detailed Procedure for Preparation and Testing a Sample

Having established reasons for certain of the critical operations in the test procedure, we now give in sequential order the detailed preparation and testing of an asphalt.

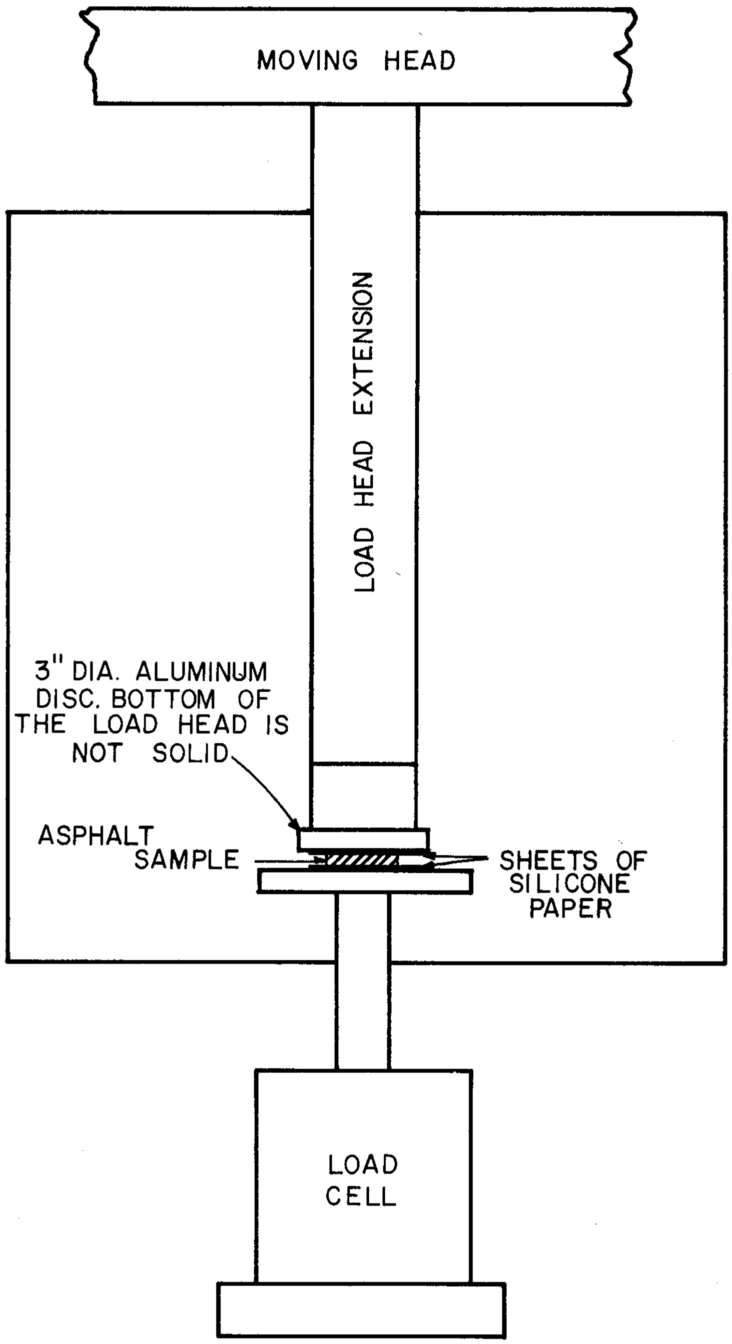
a. Preparation of Sample

Place about 30 ml of the asphalt in a 100 or 150 ml glass beaker and heat for 30 minutes in an air oven to about 225°F, which is about 100°F above its softening point. Do not use asphalt that has been melted in the laboratory more than once. While the asphalt is being heated, lightly coat the aluminum mold (shown in Figure III-a, facing) with Dow Corning Vacuum Silicone grease and place it on a sheet of Silicone treated paper. (Daubert Chemical Company's-grade 1-78e SCK-1F Release Paper, which is a lightweight paper coated on one side with silicone, was used.) This is done to prevent asphalt from adhering to the mold or table. If the mold has just been used if must be adjusted to room temperature. Pour into each mold enough asphalt to bring the surface of the molten asphalt about 1 millimeter above the surface of the aluminum mold. Place a small sheet of silicone coated paper cut to the same shape as the pressing plate (notch included) on top of the warm asphalt (Figures III-b and III-c, facing). The silicone coated side of the paper should always be in contact with the asphalt.

Align the notch in the pressing plate and silicone treated paper so the extruded asphalt can escape when pressure is applied.

Apply pressure to the top of the pressing plate so that all excess asphalt is extruded through the notch. A pressure of about 220 kilograms (100 pounds) must be applied to obtain this result. Then, place a 22 kilogram (10 pounds) weight on the sample for 2 or 3 minutes. Extreme care must be used to assure that the pressing plate does not move horizontally because the sample will be ruined if the pressing plate slides under the pressure. As asphalt is extruded it should be removed from the notch with a small steel spatula lightly coated with silicone grease. It should take about 5 minutes to complete preparation of the test specimen. After all of the asphalt has been extruded wait 15 minutes, remove the weight, pressure plate, and silicone paper and smooth off the exposed part of the sample. This entire operation will require about 20 minutes.

Immediately place the mold and sample (resting on the silicone paper) in the temperature controlled refrigerator which has been brought to the desired test temperature. Do not tilt the filled mold because the sample can still flow slightly. Allow the sample and mold to cool for 60 minutes, take it from the temperature controlled cabinet, remove the silicone coated



NOT TO SCALE

INSTRON LOAD CELL AND SAMPLES

FIGURE IV

paper from the bottom of the mold and gently push the disc of asphalt from the mold. Then, by means of a soft cloth, gently wipe excess silicone grease from the edge of the sample. If in this cleaning operation the sample bends slightly, flatten it again by gently pressing on its surface with the fingers. Immediately measure the thickness of the sample in centimeters to the 4th decimal place using a rachet type micrometer.

Place the cold sample on a fresh 3- x 3-inch piece of silicone treated paper. Then wrap the sample with a 9- or 10-inch strip of 3M Scotch Filament Tape, Pressure Sensitive 880, torn so its width is approximately the same as the thickness of the sample. The tape can be most easily applied by getting it properly aligned and then slowly rotating the sample and the paper while guiding the tape around the circumference of the sample. This procedure will require 5 minutes.

Now, put the prepared sample back in the controlled refrigerator and after 15 minutes place in the environmental cabinet of the Instron Testing machine which has meanwhile been brought to the test temperature. Center the sample and the 3- x 3-inch piece of silicone coated paper on the bottom plate of the Tester which is connected to the load cell (Figure IV, facing). Place another 3- x 3-inch piece of silicone treated paper on the top of the disc of asphalt followed by a disc of aluminum 1/2 inch thick and 3 inches in diameter. The aluminum plate is necessary because the Instron load head extension has an opening in the center and would not transmit a uniform load to the entire surface of the asphalt sample. Close the door of the environmental cabinet and wait 5 minutes for the temperature to stabilize. Thus, about 105 minutes will be required to fully prepare the sample for testing.

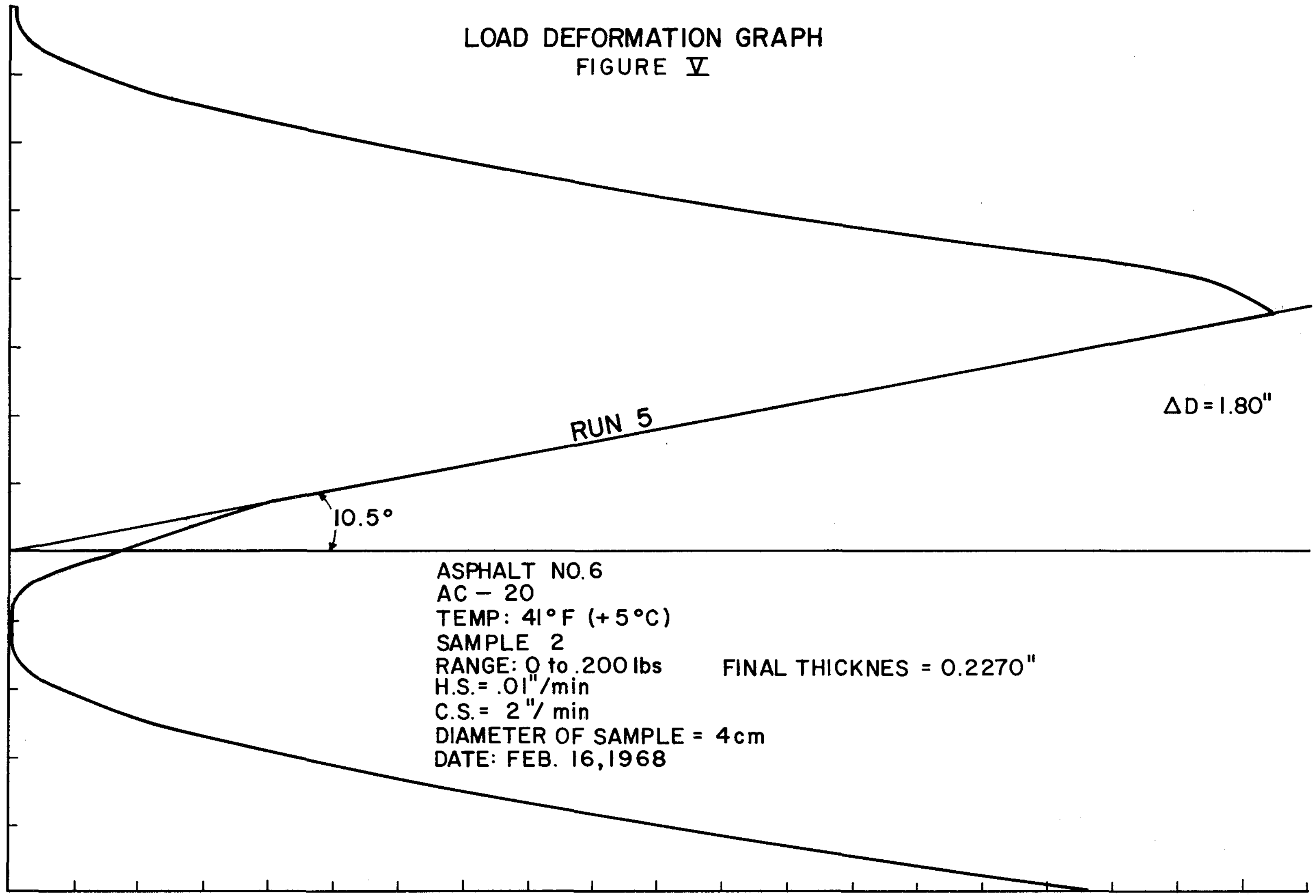
b. Instron Test

The Instron machine was calibrated, balanced and adjusted to zero before starting a test. Also, it was balanced again after each sample and aluminum plate were placed on the load cell.

In the experiments described in this report a chart speed of 2 inches per minute and a head speed of 0.01 inch per minute were used. Full scale load was 200 pounds and this was applied and released 5 times. In calculating the flow properties of a sample only the graphs obtained from the final two loadings (4th & 5th) were used because the sample was compacting during the earlier loadings.

Thickness of sample was again measured to the fourth decimal place upon completion of the final (5th) loading.

LOAD DEFORMATION GRAPH
FIGURE V



9. Calculations

As mentioned previously five full-scale loadings of 200 pounds were made on each sample at a specified temperature. Calculations were made only on the 4th and 5th loadings, because the sample was still adjusting in thickness and levelness under the first three loading runs.

The load-deformation graph (Figure V, facing) obtained from the Instron machine is curved initially but becomes a straight line for most of the loading. This straight line portion is extended over the range 0 to 200 lbs. and used for purposes of computations. The initial curvature is considered to be due to initial seating problems and to slight paper compression. The slope of the line is noted for comparison purposes between different loading runs. A horizontal base line is drawn from the point where the straight line portion of the curve intersects the vertical line corresponding to zero 'load'. The vertical distance of the point on the straight line extension of the curve corresponding to the load of 200 lbs. is measured from this base line, which is termed as 'ΔD' (refer to Instron chart enclosed). This 'ΔD' is used in computation of strain. The stress is calculated as load divided by area.

The stiffness and energy are calculated as follows:

$$\text{Stiffness} = \text{Stress}/\text{Strain}$$

$$\text{Energy} = 1/2\ \text{Stress} \times \text{Strain}$$

A complete set of calculations are shown on the following pages for run 5 on a sample of Asphalt No. 6, grade AC-20 at 5°C(41°F).

Three samples are tested at each temperature for a particular asphalt and the average of the two closest values is reported.

ASPHALT NO. 6,
AC - 20

HEAD SPEED = .01"/min
CHART SPEED = 2"/min
RANGE: 0 to 200 lbs
DIAMETER: 4 cms

TEMPERATURE: 41°F (+5°C)
DATE: FEB. 16, 1968

SAMPLE 2

FINAL THICKNESS, h: =0.2270" (0.5766 cms) = h.

RUN 5:

$\Delta D = 1.80"$ SLOPE = 10.5°

$$\text{STRAIN} = \frac{\Delta h}{h}$$

$$\Delta L = \frac{\text{HEAD SPEED}}{\text{CHART SPEED}} \times \Delta D$$

$$= \frac{.01}{2} \times \Delta D = .005 \quad \Delta D \text{ inches}$$

$$\text{STRAIN} = \frac{0.005 \times \Delta D}{h} = \frac{.005 \times 1.80}{0.227} = 3.96 \times 10^{-2} \text{ in/in or cm/cm}$$

STRESS = P/A = LOAD / AREA

LOAD = 200 lbs = 200 lbs X 453.6 gms/lb.

$$\text{AREA} = \pi \gamma^2 = \frac{22}{7} \times 2^2 \text{ sq. cms.}$$

$$\text{STRESS} = \frac{200 \times 453.6}{\frac{22}{7} \times 4} = 7216 \text{ gms/cm}^2$$

$$\text{STIFFNESS} = \text{STRESS/STRAIN}$$

$$= \frac{7216 \text{ gms/cm}^2}{3.96 \times 10^{-2} \text{ cm/cm}} = 182{,}000 \text{ gms/cm}^2$$

$$\text{ENERGY} = \frac{1}{2} \times \text{STRESS} \times \text{STRAIN}$$

$$= \frac{1}{2} \times 7216 \text{ gms/cm}^2 \times 3.96 \times 10^{-2} \text{ cm/cm}$$

$$= 143 \quad \text{gms-cm/cm}^3$$

VIII APPENDIX

Section	Title	Page

1. Original Data for Stiffness of Asphalts

TABLES

FIGURES

Section 1-a

<u>Original Data</u>
<u>Asphalt No. 3</u>
<u>Grade AC-10</u>

Data at 5, -5, and -15°C
are all very satisfactory

Table A-1

Compression Tests on Asphalt No. 3
Grade AC-10
Stiffness Values

Temperature: 5°C (41°F)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2283 in. (0.5799 cm.)
Sample 2, 0.2280 in. (0.5791 cm.)
Sample 3, 0.2311 in. (0.5870 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	13.0	12.0	12.2	141,400	155,200	156,600
5	13.0	12.0	12.0	143,300	156,700	158,800
Avg.	13.0	12.0	12.1	142,300	156,000	157,700

Average of Best 2 Samples

Samples Used	Slope	Stiffness
2	12.0	156,700
3	12.1	157,700
Avg.	12.05	157,200

Table A-1, cont.

Temperature: $-5^{o}C$ ($23^{o}F$)
Diameter of Samples: 4 cms.
Final thickness of:
Sample 1, 0.2276 in. (0.5781 cm.)
Sample 2, 0.2285 in. (0.5804 cm.)
Sample 3, 0.2275 in. (0.5779 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	11.0	11.0	10.5	175,700	173,600	176,500
5	11.0	11.0	10.5	175,700	175,400	176,500
Avg.	11.0	11.0	10.5	175,700	174,500	176,500

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	11.0	175,700
2	11.0	174,500
Avg.	11.0	175,100

Table A-1, cont.

Temperature: $-15^{o}C$ ($5^{o}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2312 in. (0.5872 cm.)
Sample 2, 0.2310 in. (0.5867 cm.)
Sample 3, 0.2290 in. (0.5817 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	10.2	10.2	10.0	191,800	190,500	197,900
5	10.0	10.0	9.8	195,100	192,700	200,300
Avg.	10.1	10.1	9.9	193,400	191,600	199,100

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	10.1	193,400
2	10.1	191,600
Avg.	10.1	192,500

Table A-2

Average Slope and Stiffness for Asphalt No. 3 Grade AC-10 for Temperatures Used

Diameter of Sample: 4 cm.
Head Speed: 0.01 inch/minute
Chart Speed: 2.0 inches/minute
Load Range: 0-200 lbs.

Temp.	Avg. Slope	Avg. Stiffness
+5°C	12.05	157,200
-5°C	11.0	175,100
-15°C	10.1	192,500

See Figure A-1 for Plot of these Data.

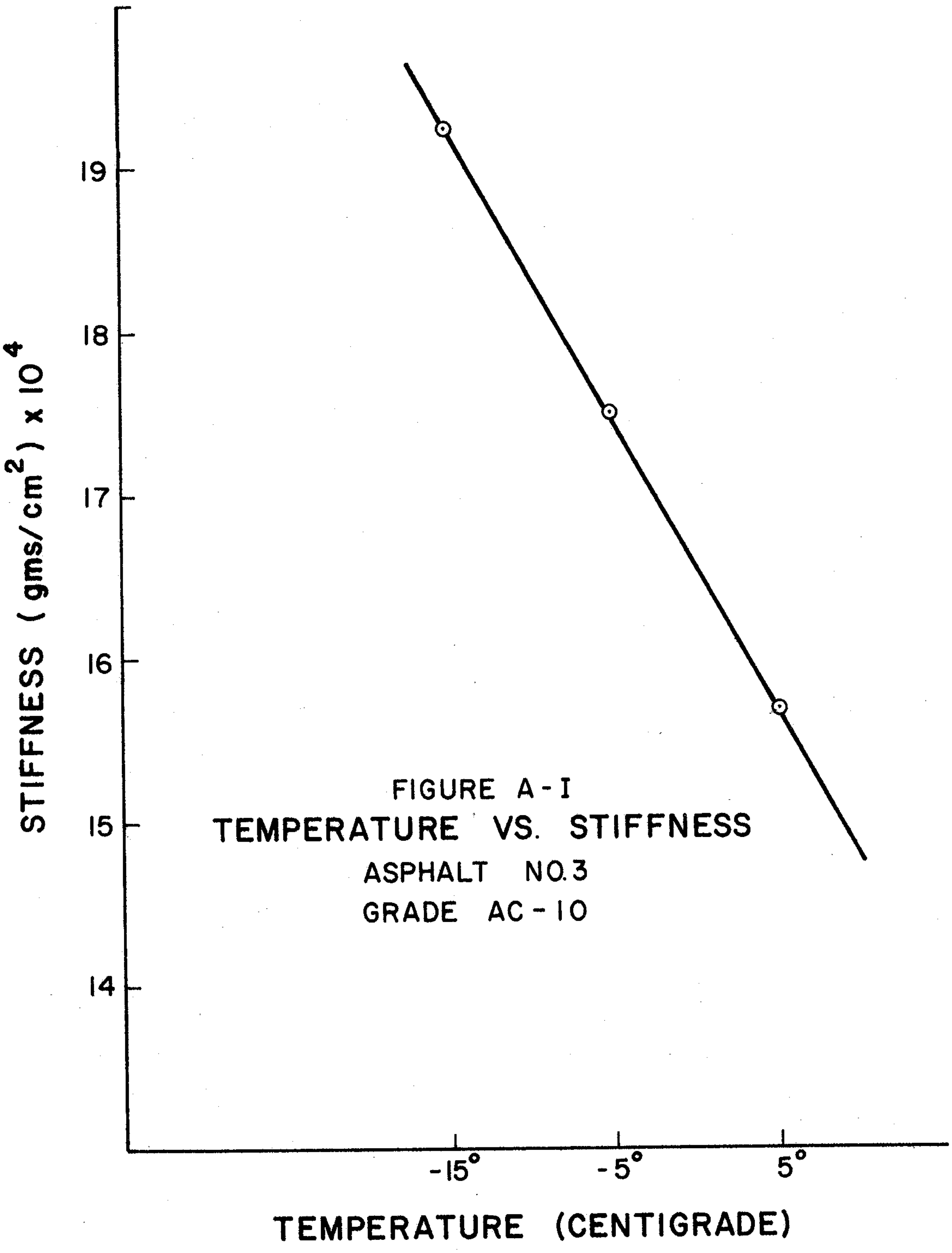


FIGURE A-I
TEMPERATURE VS. STIFFNESS
ASPHALT NO.3
GRADE AC-10

Section 1-b

<u>Original Data</u>
<u>Asphalt No. 3</u>
<u>AC-20 Grade</u>

Value of Stiffness at -15°C is much too low

Table A-3

Compression Tests on Asphalt No. 3
Grade AC-20
Stiffness Values

Temperature: 5°C (41°F)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2294 in. (0.5827 cm.)
Sample 2, 0.2303 in. (0.5850 cm.)
Sample 3, 0.2305 in. (0.5855 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	11.5	11.5	11.0	168,000	160,600	175,100
5	11.5	11.5	11.0	169,800	163,700	178,800
Avg.	11.5	11.5	11.0	168,900	162,100	177,000

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	11.5	168,900
2	11.5	162,100
Avg.	11.5	165,500

Table A-3, cont.

Temperature: $-5^{o}C$ ($23^{o}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2267 in. (0.5758 cm.)
Sample 2, 0.2265 in. (0.5753 cm.)
Sample 3, 0.2271 in. (0.5768 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	9.5	10.0	10.5	192,500	189,000	182,100
5	9.5	10.0	10.0	192,500	189,000	184,100
Avg.	9.5	10.0	10.25	192,500	189,000	183,100

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	9.5	192,500
2	10.0	189,000
Avg.	9.75	190,700

Table A-3, cont.

Temperature: $-15^{\circ}C$ ($+5^{\circ}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2307 in. (0.5860 cm.)
Sample 2, 0.2309 in. (0.5865 cm.)
Sample 3, 0.2272 in. (0.5771 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	10.8	11.0	10.0	180,000	174,500	182,200
5	10.8	10.5	10.0	182,900	183,000	187,400
Avg.	10.8	10.75	10.0	181,500	178,800	184,800

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	10.8	181,500
3	10.0	184,800
Avg.	10.4	183,100

Table A-4

Average Slope and Stiffness for Asphalt No. 3 Grade AC-20 for Temperatures Used

Diameter of Sample: 4 cms.
Head Speed: 0.01 inch/minute
Chart Speed: 2.00 inches/minute
Load Range: 0-200 lbs.

Temperature	Average Slope	Average Stiffness
+5°C	11.5	165,500
-5°C	9.75	190,700
-15°C	10.4	183,100

See Figure A-II for Plot of these Data

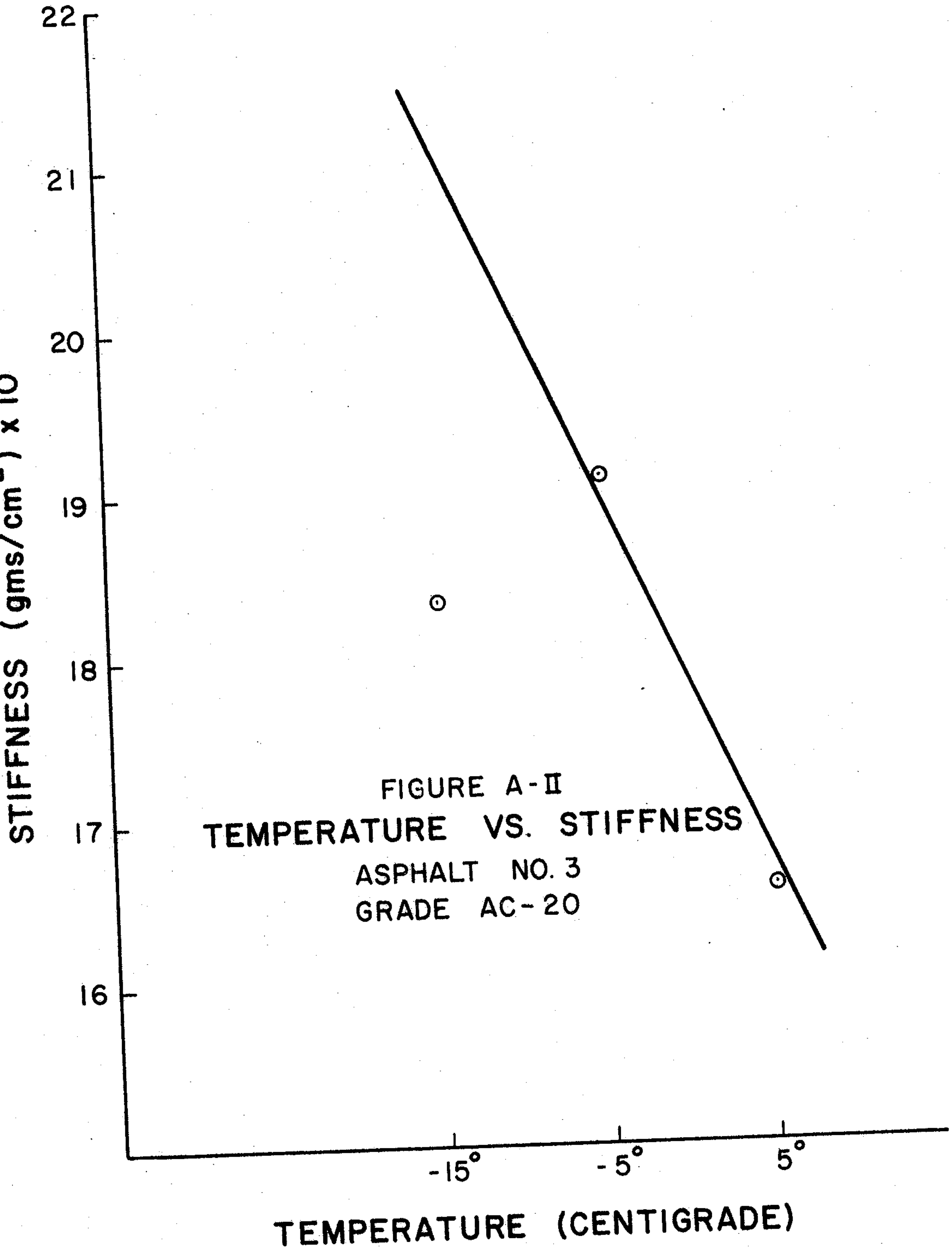


FIGURE A-II
TEMPERATURE VS. STIFFNESS
ASPHALT NO. 3
GRADE AC-20

Section 1-c

Original Data
Asphalt No. 6
Grade AC-10

Value of Stiffness at -15°C is much too low

Table A-5

Compression Tests on Asphalt No. 6
Grade AC-10
Stiffness Values

Temperature: 5°C (41°F)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2300 in. (0.5842 cm.)
Sample 2, 0.2290 in. (0.5817 cm.)
Sample 3, 0.2284 in. (0.5801 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	12.0	11.0	11.5	160,400	171,300	162,400
5	12.0	11.0	11.5	161,900	170,400	164,000
Avg.	12.0	11.0	11.5	161,150	170,900	163,200

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	12.0	161,150
3	11.5	163,200
Avg.	11.75	162,200

Table A-5, cont.

Temperature: $-5^{o}C$ ($23^{o}F$)
Diameter of Sample: 4 cms.
Final Thickness of:
Sample 1, 0.2271 in. (0.5768 cm.)
Sample 2, 0.2283 in. (0.5799 cm.)
Sample 3, 0.2305 in. (0.5855 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	9.0	9.0	9.0	207,400	216,800	207,900
5	9.0	8.5	8.5	207,400	224,100	217,400
Avg.	9.0	8.75	8.75	207,400	220,500	212,700

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	9.0	207,400
3	8.75	212,700
Avg.	8.87	210,000

Table A-5, cont.

Temperature: $-15^{o}C$ ($5^{o}F$)
Diameter of Sample: 4 cms.
Final Thickness of:
  Sample 1, 0.2277 in. (0.5784 cm.)
  Sample 2, 0.2314 in. (0.5878 cm.)
  Sample 3, 0.2311 in. (0.5870 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	11.0	10.5	11.0	180,600	185,500	181,300
5	11.0	10.5	10.0	186,700	185,500	191,700
Avg.	11.0	10.5	10.5	183,700	185,500	186,500

Average of Best 2 Samples

Samples Used	Slope	Stiffness
2	10.5	185,500
3	10.5	186,500
Avg.	10.5	186,000

Table A-6

Average Slope and Stiffness
for Asphalt No. 6 Grade AC-10
for Temperatures Used

Diameter of Sample: 4 cms.
Head Speed: 0.01 inch/minute
Chart Speed: 2.00 inches/minute
Load Range: 0-200 lbs.

Temperature	Average Slope	Average Stiffness
+5°C	11.75	162,200
-5°C	8.87	210,000
-15°C	10.5	186,000

See Figure A-III for Plot of these Data

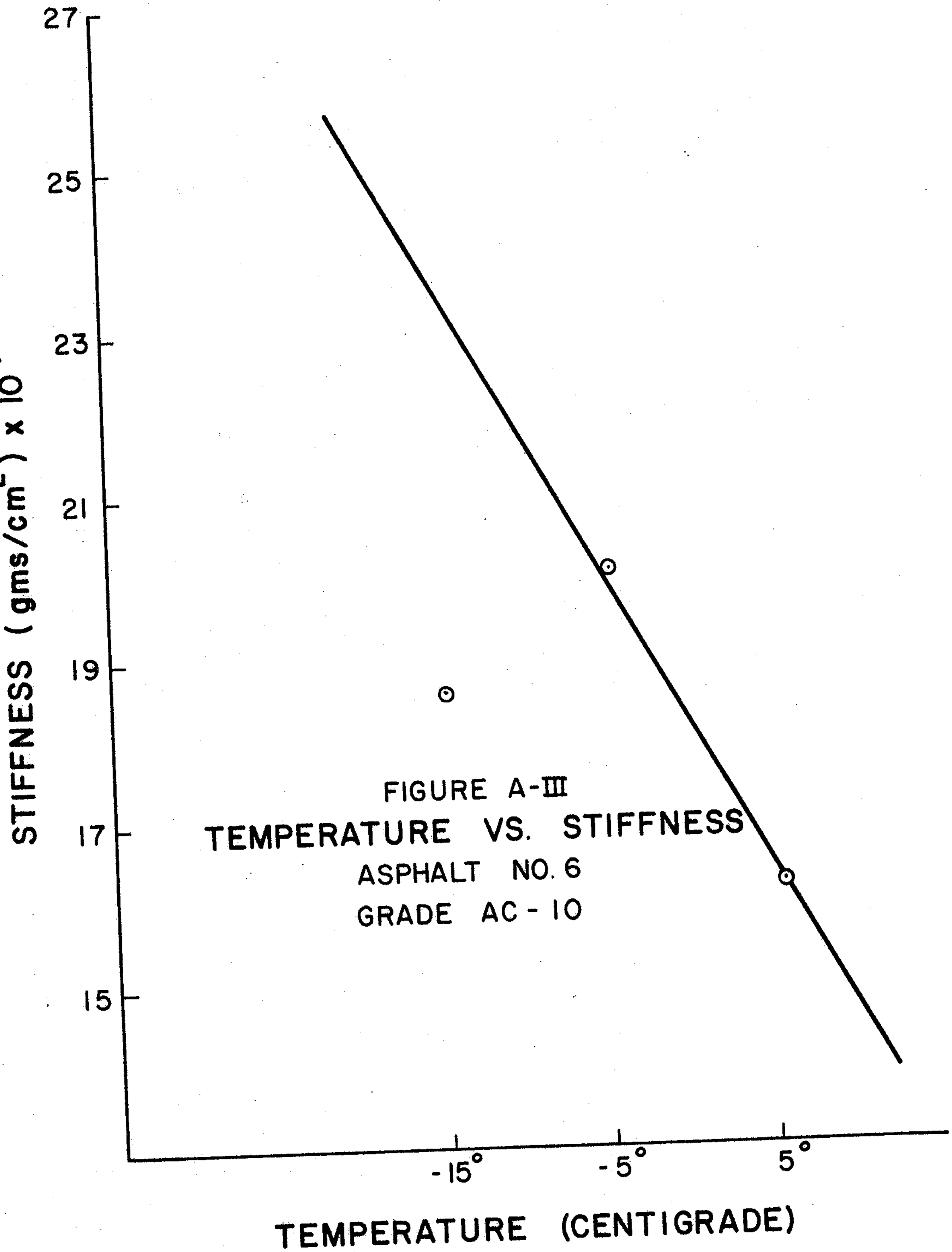


FIGURE A-III
TEMPERATURE VS. STIFFNESS
ASPHALT NO. 6
GRADE AC - 10

Section 1-d

<u>Original Data</u>
<u>Asphalt No. 6</u>
<u>Grade AC-20</u>

Value of Stiffness at -15°C
is much too low

Table A-7

Compression Tests on Asphalt No. 6
Grade AC-20
Stiffness Values

Temperature: 5°C (41°F)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2273 in. (0.5773 cm.)
Sample 2, 0.2270 in. (0.5766 cm.)
Sample 3, 0.2280 in. (0.5791 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	11.5	11.0	11.0	170,000	175,200	171,400
5	11.0	10.5	10.5	176,400	182,000	176,900
Avg.	11.25	10.75	10.75	173,200	178,600	174,200

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	11.25	173,200
3	10.75	174,200
Avg.	11.0	173,700

Table A-7, cont.

Temperature: $-5^{o}C$ ($23^{o}F$)
Diameter of Sample: 4 cms.
Final Thickness of:
Sample 1, 0.2308 in. (0.5862 cm.)
Sample 2, 0.2304 in. (0.5852 cm.)
Sample 3, 0.2293 in. (0.5824 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	9.0	9.5	9.0	216,300	204,000	194,700
5	8.5	9.0	9.0	226,600	207,800	208,100
Avg.	8.75	9.25	9.0	221,500	205,900	201,400

Average of Best 2 Samples

Samples Used	Slope	Stiffness
2	9.25	205,900
3	9.0	201,400
Avg.	9.12	203,700

Table A-7, cont.

Temperature: -15°C (5°F)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2273 in. (0.5773 cm.)
Sample 2, 0.2380 in. (0.6045 cm.)
Sample 3, 0.2307 in. (0.5860 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	11.0	9.5	9.0	181,200	212,000	205,500
5	10.0	10.0	9.0	188,500	202,100	205,500
Avg.	10.5	9.75	9.0	184,900	207,000	205,500

Average of Best 2 Samples

Samples Used	Slope	Stiffness
2	9.75	207,000
3	9.0	205,500
Avg.	9.36	206,300

Table A-8

Average Slope and Stiffness for Asphalt No. 6 Grade AC-20 for Temperatures Used

Diameter of Sample: 4 cms
Head Speed: 0.01 inch/minute
Chart Speed: 2.0 inches/minute
Load Range: 0-200 lbs.

Temperature	Average Slope	Average Stiffness
+5°C	11.0	173,700
-5°C	9.12	203,700
-15°C	9.36	206,300

See Figure A-IV for Plot of these Data

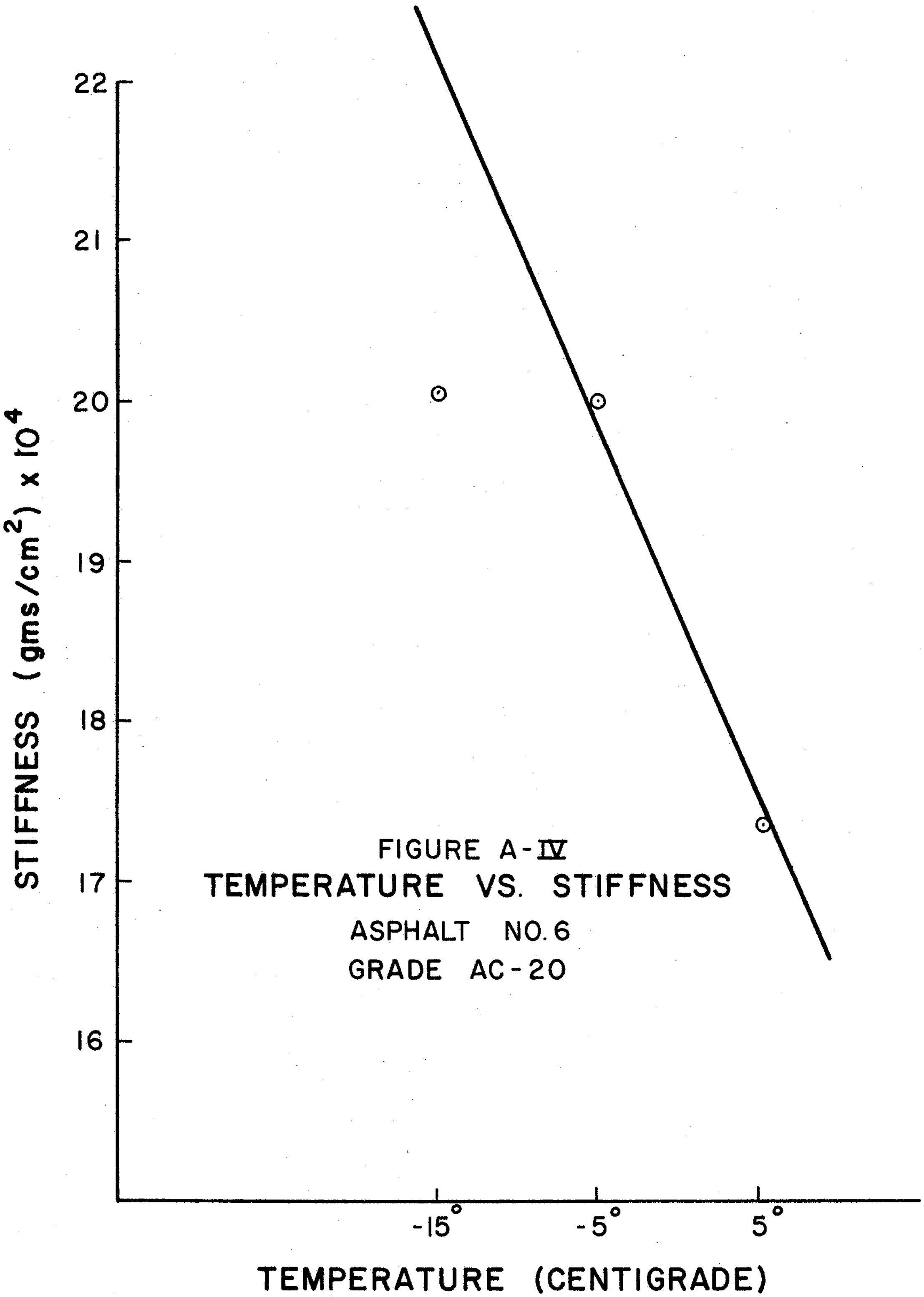


FIGURE A-IV
TEMPERATURE VS. STIFFNESS
ASPHALT NO. 6
GRADE AC-20

Section 1-e

<u>Original Data</u>
<u>Asphalt No. 11</u>
<u>Grade AC-10</u>

Data at 5, -5, and -15°C
are all fairly satisfactory

Table A-9

Compression Tests on Asphalt No. 11
Grade AC-10
Stiffness Values

Temperature: 5°C (41°F)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2305 in. (0.5855 cm.)
Sample 2, 0.2300 in. (0.5842 cm.)
Sample 3, 0.2301 in. (0.5845 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	12.0	12.0	12.0	160,700	159,600	156,600
5	12.0	12.0	12.0	160,700	161,900	156,600
Avg.	12.0	12.0	12.0	160,700	160,800	156,600

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	12.0	160,700
2	12.0	160,800
Avg.	12.0	160,750

Table A-9, cont.

Temperature: $-5^{o}C$ ($23^{o}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2302 in. (0.5847 cm.)
Sample 2, 0.2300 in. (0.5842 cm.)
Sample 3, 0.2288 in. (0.5812 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	11.0	11.0	11.5	168,600	175,600	165,900
5	11.0	11.0	11.5	168,600	179,400	167,600
Avg.	11.0	11.0	11.5	168,600	177,500	166,800

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	11.0	168,600
3	11.5	166,800
Avg.	11.25	167,700

Table A-9, cont.

Temperature: $-15^{o}C$ ($5^{o}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2330 in. (0.5918 cm.)
Sample 2, 0.2282 in. (0.5796 cm.)
Sample 3, 0.2280 in. (0.5791 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	10.5	10.8	12.0	185,800	177,000	162,900
5	10.0	10.2	11.5	192,200	185,000	175,000
Avg.	10.25	10.5	11.75	189,000	181,000	169,000

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	10.25	189,000
2	10.50	181,000
Avg.	10.38	185,000

Table A-10

Average Slope and Stiffness
for Asphalt No. 11 Grade AC-10
for Temperatures Used

Diameter of Samples: 4 cms.
Head Speed: 0.01 inch/minute
Chart Speed: 2.0 inches/minute
Load Range: 0-200 lbs.

Temperature	Average Slope	Average Stiffness
+5°C	12.0	160,750
-5°C	11.25	167,700
-15°C	10.38	185,000

See Figure A-V for Plot of these Data

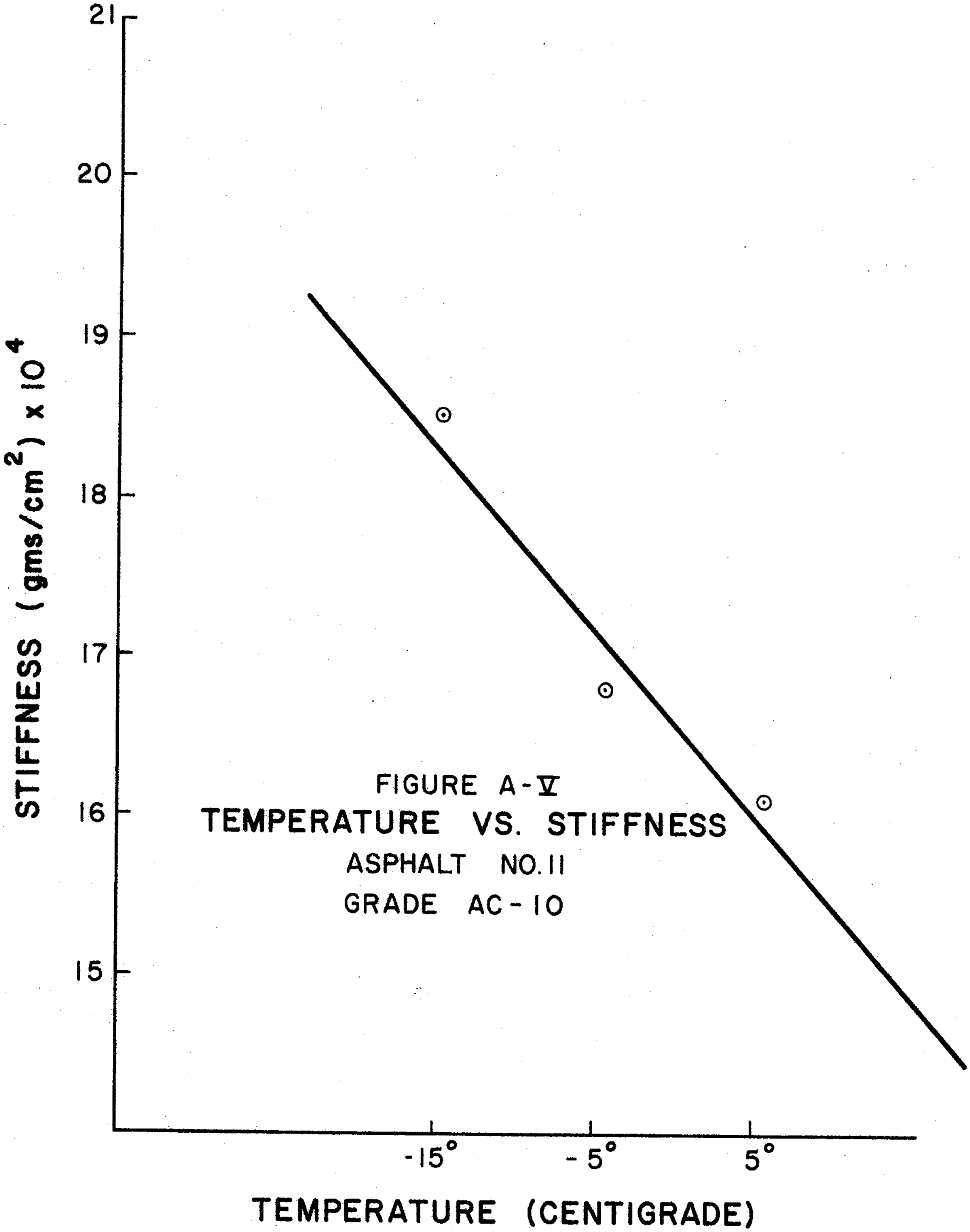


FIGURE A-V
TEMPERATURE VS. STIFFNESS
ASPHALT NO. 11
GRADE AC-10

Section 1-f

Original Data
Asphalt No. 11
Grade AC-20

Data at 5°, -5° and -15°F
are all fairly satisfactory

Table A-11

Compression Tests on Asphalt No. 11
Grade AC-20
Stiffness Values

Temperature: $5^{o}C$ ($41^{o}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2275 in. (0.5779 cm.)
Sample 2, 0.2290 in. (0.5817 cm.)
Sample 3, 0.2301 in. (0.5845 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	12.0	12.0	13.0	154,900	156,600	147,600
5	12.0	11.6	12.6	154,900	162,800	151,600
Avg.	12.0	11.8	12.8	154,900	159,700	149,600

Average of 2 Best Samples

Samples Used	Slope	Stiffness
1	12.0	154,900
2	11.8	159,700
Avg.	11.9	157,300

Table A-11, cont.

Temperature: $-5^{o}C$ ($23^{o}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2280 in. (0.5791 cm.)
Sample 2, 0.2273 in. (0.5773 cm.)
Sample 3, 0.2324 in. (0.5903 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees) 1	2	3	Stiffness (gm/cm^2) 1	2	3
4	11.5	12.0	10.5	162,900	152,600	204,500
5	11.5	11.6	10.5	164,500	166,500	207,000
Avg.	11.5	11.8	10.5	163,700	159,550	205,800

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	11.5	163,700
2	11.8	159,550
Avg.	11.65	161,600

Table A-11, cont.

Temperature: $-15^{o}C$ ($5^{o}F$)
Diameter of Samples: 4 cms.
Final Thickness of:
Sample 1, 0.2245 in. (0.5702 cm.)
Sample 2, 0.2305 in. (0.5855 cm.)
Sample 3, 0.2355 in. (0.5982 cm.)

Loading Cycle No.	Slope of Stress-Strain Curve (Degrees)			Stiffness (gm/cm^2)		
	1	2	3	1	2	3
4	10.5	10.0	11.0	174,200	191,200	180,800
5	10.5	10.0	11.6	178,000	191,200	177,000
Avg.	10.5	10.0	11.3	176,100	191,200	178,900

Average of Best 2 Samples

Samples Used	Slope	Stiffness
1	10.5	176,100
3	11.3	178,900
Avg.	10.9	177,500

Table A-12

<u>Average Slope and Stiffness of Asphalt No. 11 Grade AC-20 for Temperatures Used</u>

Diameter of Samples; 4 cms.
Head Speed: 0.01 inch/minute
Chart Speed: 2.0 inches/minute
Load Range: 0-200 lbs.

Temperature	Average Slope	Average Stiffness
$+5^{o}C$	11.9	157,300
$-5^{o}C$	11.65	161,600
$-15^{o}C$	10.9	177,500

See Figure A-VI for Plot of these Data

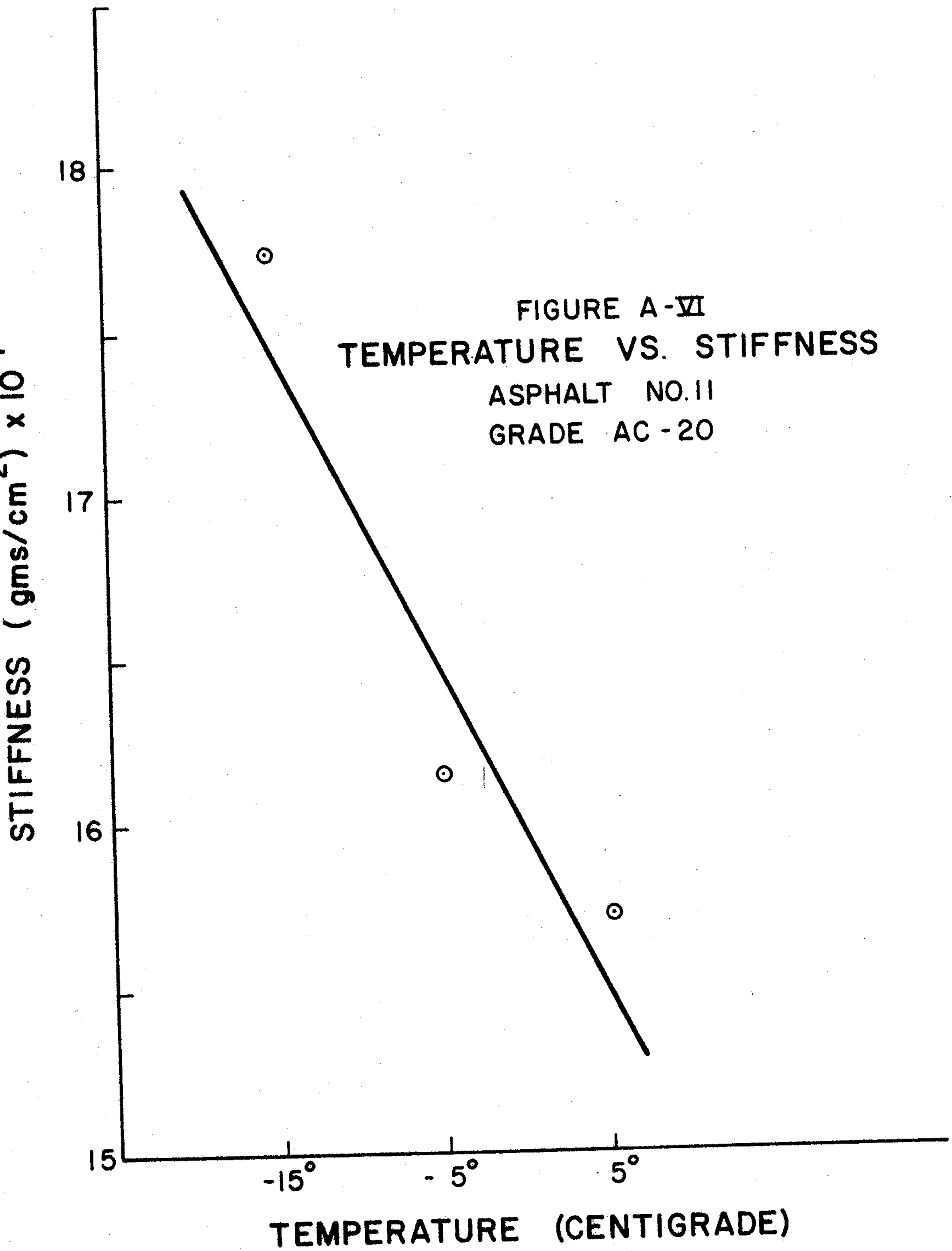


FIGURE A-VI
TEMPERATURE VS. STIFFNESS
ASPHALT NO. 11
GRADE AC-20
STIFFNESS (gms/cm²) x 10⁴
18
17
16
15
-15°
-5°
5°
TEMPERATURE (CENTIGRADE)

SECTION 2

Average Stiffness Values for Asphalt No. 3, AC-10 and AC-20 Grades at 5, -5 and -15°C

Average values were taken from the curves shown in Figures VI and VII of Section 10a and 10b, pages 33 and 39. The corrected values are shown in the following tabulation:

Corrected Values for Stiffness

Asphalt No.	Grade	Temperature °C	Temperature °F	Stiffness gm/cm²
3	AC-10	5	41	156,900
3	AC-10	-5	23	174,700
3	AC-10	-15	5	192,500
3	AC-20	5	41	167,000
3	AC-20	-5	23	189,000
3	AC-20	-15	5	212,000

SECTION 3

Average Stiffness Values for Asphalt No. 6, AC-10 and AC-20 Grades at 5, -5 and -15°C

Average values were taken from the curves shown in Figures VIII and IX of Section 10c and 10d, pages 45 and 51. Corrected values are shown in the following tabulation:

Corrected Values for Stiffness

Asphalt No.	Grade	Temperature °C	Temperature °F	Stiffness gm/cm^2
6	AC-10	5	41	162,200
6	AC-10	-5	23	199,000
6	AC-10	-15	5	235,000
6	AC-20	5	41	175,000
6	AC-20	-5	23	198,200
6	AC-20	-15	5	221,600

SECTION 4

Average Stiffness Values for Asphalt No. 11, AC-10 and AC-20 Grades at 5, -5 and -15°C

Average values were taken from the curves shown in Figures X and XI of Section 10e and 10f, pages 59 and 63. Corrected values are shown in the following tabulation:

Corrected Values for Stiffness

Asphalt No.	Grade	Temperature °C	Temperature °F	Stiffness gm/cm²
11	AC-10	5	41	154,800
11	AC-10	-5	23	169,000
11	AC-10	-15	5	183,300
11	AC-20	5	41	154,700
11	AC-20	-5	23	164,600
11	AC-20	-15	5	174,500