A STUDY OF ASPHALT BRIDGE PLANK

by

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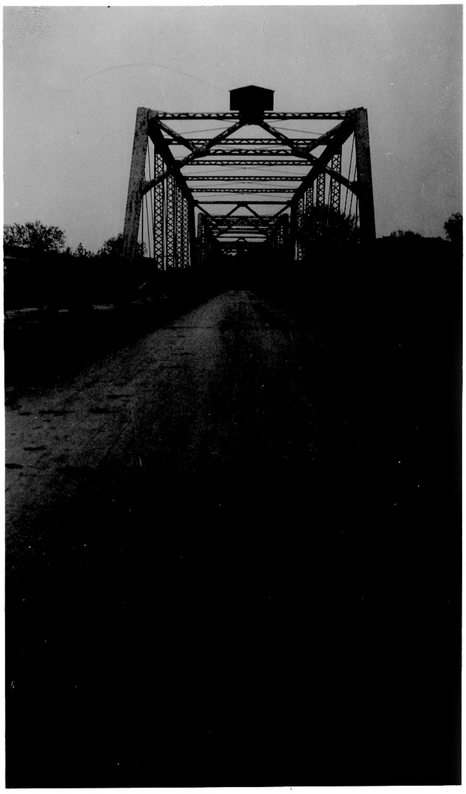


Asphalt Bridge Plank Surface in Excellent Condition; Laid in 1928 on the Kansas River Bridge East of Manhattan, Kansas on Route 13.

INTRODUCTION

The tremendous development of highway traffic resulting from the operation of over 26,000,000 motor vehicles in the United States has created demands for bridge wearing surfaces which are effective under all kinds of traffic, highly resistant to wear, resilient, and shock absorbing, durable, safe and quiet. Cognizance has been taken of these rapidly growing demands, and attempts have been made to produce bridge wearing surfaces possessing the above mentioned characteristics. Preformed asphalt planks probably are the most recent development in bridge wearing surfaces.

For sometime prior to 1925 the Philip Carey Company of Cincinnati, Ohio had in operation a process for the manufacture of Rail Filler. Rail Filler consists of sections of asphaltic composition material shaped to fit any track rail section. It is applied as a cushion between the sides of the rail and the adjacent pavement. In the early spring of 1925 the Philip Carey engineers conceived the idea of making asphaltic composition in the shape of rectangular cross sections and experimenting with these sections as a wearing surface under traffic. This was done. The ingredients were asphalt, fibre, and mineral aggregate, mixed together in a heated mixer and extruded in a steam jacketed machine through a die having an orifice conforming to the shape and size of the planks desired.

The first applications of asphalt planks were laid as paving on two small railway crossings in northeastern Ohio. Several other small installations were made during the same year. The first application of asphalt plank as a bridge flooring material was in 1926 when about a dozen such pavements were laid. From this very small beginning asphalt plank made rapid strides. It attracted a good deal of attention on the part of highway and bridge engineers, and finally began to be advertised in engineering publications. In 1928 this type of flooring was installed on the La Salle street bridge in Chicago.

Although the Philip Carey Company was alone in the manufacture of asphalt planks for several years, their success attracted others into the field with the result that at the present time there are six or seven manufacturers more or less active in the making and selling of this type of material.

While asphalt plank is not an old material and has had little opportunity to establish itself in durability tests, engineers have watched its performance closely. On several installations now in service it has shown great durability under traffic and seems to suffer no appreciable wear. It absorbs shocks, and has shown no tendency to crack or splinter under vibration and traffic. It has proved valuable in decreasing traffic noises. In many cases it has shown its superiority over other traffic surfaces now in use and it appears to embrace all the important qualities which make an ideal wearing surface for bridges.

Considerable research work has been done by the various manufacturers of asphalt plank in the development of their products. Asphalts of different penetrations, fibres of various kinds, and mineral aggregates of a great many different kinds and forms have been studied. Almost all possible combinations of these materials have been made the subject of careful research and investigation. In 1929 the Johns Manville Company of New York authorized the expenditure of a considerable sum of money for research work on asphalt plank. Three engineers worked at the Dayton plant for several months experimenting with various formulas, testing machines, and synthetic mixes. Following this extensive period of research the Johns Manville specifications for asphalt bridge plank were issued.

It is interesting to note also that while the larger amount of asphalt planks is undoubtedly used as bridge flooring, a considerable amount is used for flooring purposes in industrial plants and other similar locations, especially where it is not subjected to standing loads. Planks intended for this use, however, are different from planks used for bridge flooring. Still another important application is as a protection course laid over membrane waterproofing.

Purpose

Although various manufacturers have carried on some research on asphalt planks and proposed specifications, no research work has been done by disinterested engineers. There are no standard specifications for determining the suitability of asphalt planks for use as bridge flooring. With the exception of an 8-page pamphlet published in 1930 by one of the manufacturers* of the planks, there is no technical literature available on asphalt planks.

In view of these facts it became the purpose of this research to study the physical properties of several brands of asphalt planks now on the market. The objective was to secure data which could be used as a basis for determining the suitability of asphalt planks for use as bridge wearing surfaces.

* This manufacturer is at present revising his specifications and proposed methods of tests because they have been found unsuitable.

REQUIREMENTS OF A BRIDGE PLANK

General

In order that a plank be suitable for use as the wearing surface of a bridge it should possess several important qualities. The physical properties of the material should enable it to resist shock, to sustain the stationary and moving loads of modern traffic, to be non-shatterable, durable, non-absorbent, and non-corrugating under vehicular traffic. It should be also resistant to wear and have a suitable tractive surface. The compressive and shearing action caused by a vehicle and its load has a tendency to break down the surface of a bridge. Thus it is evident that a suitable plank must be sufficiently strong in compression and shear to withstand the heaviest loads caused by traffic. The shearing action is more pronounced when the load happens to be placed near the ends or edges of a plank, or when the load may pass over a small stone or some other small obstruction that might be on the surface. Bridge planks are occasionally required to carry unusual loads such as occur when threshing machines, steam shovels, tractors, and horses pass over their surfaces. A satisfactory plank must not become damaged by such loads.

The plank should be tough and have adequate resistance to impact. It should not break or split under the hammering of the traffic loads. Extreme variation in climate should not affect the surface either by rendering it soft in summer or brittle in winter.

The surface should be light weight, resilient, and capable of absorbing vibrations so as to adequately protect the sub-floor and structure from any possible injury which might come as a result of traffic impact. It is desirable to reduce the dead weight on a bridge as much as possible. Since the floor system is the only part of the bridge where this reduction may be made, the importance of using a light weight wearing surface is evident.

The motoring public demands highway and bridge surfaces that are dustless, non-skid and safe. Surfaces which become slippery in wet or icy weather are undesirable. Sound engineering and good judgment, especially under present economic conditions, call for moderate-priced construction. Ease of application, fire resistance, ease of maintenance, and appearance are subordinate but necessary factors in a well designed bridge.

Asphalt Plank

Numerous traffic surfaces have been developed for bridge work, but with few exceptions they are costly and do not possess sufficient resiliency to protect the subfloor from injury. Rubber blocks are possibly one exception to this as they make excellent wearing surfaces when weight and cost are not governing considerations. Wood, concrete, and metal have been used, as it was thought in the past that a traffic surface should be hard. All of these surfaces are unsatisfactory. Wood, though somewhat resilient, has a tendency to splinter and ravel under the continual pounding of traffic. It is not quiet and, because it is highly absorbent, it will check and warp. Since it is short lived the cost of maintenance is high. The maximum life of a wooden bridge floor is between five and seven years. Concrete and metal possess ability to resist wear in a very high degree. They fail, however, to absorb the traffic shocks. The use of concrete increases the dead weight of the structure considerably. Metal wearing surfaces usually become noisy after a few months of service.

As pointed out above, asphalt plank has recently demonstrated its superiority as a traffic surface because it absorbs impact and dissipates the resulting forces. Experience has shown that the hardness of a surface has little to do with its performance. Asphalt plank does not possess a high degree of hardness, but it does possess the ability to yield and recover. It also knits and heals under the ironing effect of traffic. This is a desirable feature. The adjacent planks weld together so that a smooth unbroken surface results. If the nail heads are countersunk they soon become covered and thus protected from the effects of corrosion.

Manufacturers claim that this peculiar ability of asphalt plank to knit and heal under traffic is due to the percent of asphalt in the plank. Consequently it is important that there be sufficient asphalt present. If the asphalt is excessive, the plank will be too soft. Although asphalt plank is not a hard unyielding material it must offer sufficient resistance to cold flow (a term generally used by engineers to describe horizontal movement of the pavement in such a manner as to create waves in the surface). The fibrous filler is said by manufacturers to be responsible for its resistance to cold flow since the fibres interlock and mat together so that stability is maintained. Fibrous filler is generally termed mineral.

The resiliency of the plank is due to the fibre content. It is important that the fibres be of suitable material which will not decay and impair the plank. There should be sufficient fibre, well interlocked, so that the desired resilience will be obtained. It is claimed that planks low in fibre content are hard and brittle.

Asphalt plank should be non-absorbent to prevent the shrinkage and warping so prevalent in wood. For all practical purposes it should be waterproof. If the plank is not waterproof and non-absorbent, water will collect on the nails (when the plank is laid over a wooden sub-floor) and cause them to corrode and thus lose their holding power.

In form asphalt planks resemble pieces of lumber and may be handled in much the same manner in that they can be nailed and sawed. The principal difference lies in the flexibility. Some difficulties, however, have been experienced due to rough handling of the planks. Figure 1 gives an illustration of some planks which have cracked as a result of rough handling during the crating and shipping process. No. 1 is 1"x8" plank and No. 2 and No. 3 are $1\frac{1}{2}$"x8" planks. All are of the same brand, which is designated as "F" later on in this report.

At the right in Figure 2 are shown two pieces of the plank as received from the manufacturer. Plank are made in thicknesses of 1/2, 3/4, 1, 1 1/4, 1 1/2, and 2 inches, and in widths of 8 and 12 inches. They may be secured with straight sides or with ship-lap sections. The lengths obtainable are 2, 4, and 6 feet. Asphalt plank is a homogeneous mass. It is easily applied and is ready for

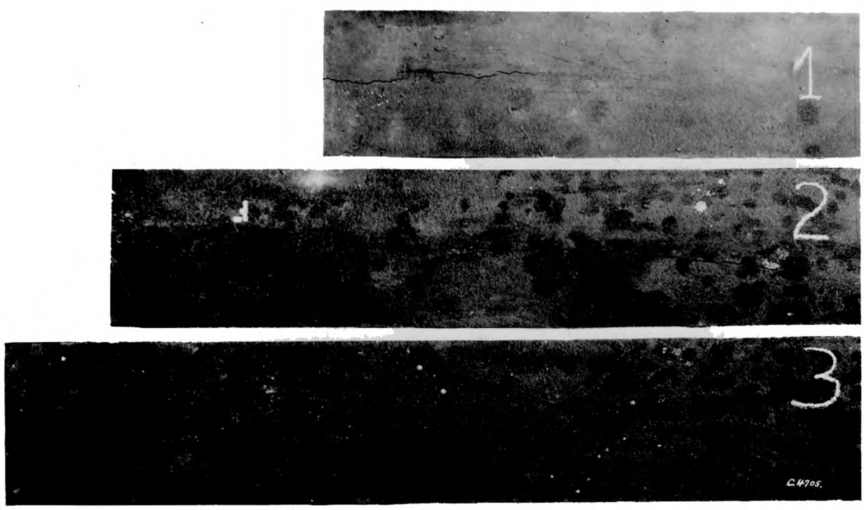


Fig. 1. Cracks in Asphalt Planks Caused by Improper Crating and Rough Handling.

traffic the moment it is laid. Traffic may be continued over the structure during application. This feature is important in eliminating detours on highways and traffic congestions in cities. In case some unusual condition results in injury to some portion of the bridge floor, it

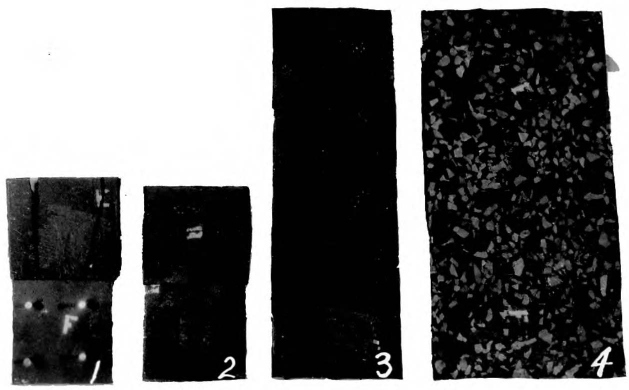


Fig. 2. Plank 1 - Sample "F" Passing and Sample "E" Failing in Cold Brittleness Test.
Plank 2 - Compression-Shear Tests.
Plank 3 - Standard 1"x8" Asphalt Bridge Plank.
Plank 4 - Special Non-Skid Surfaced Asphalt Bridge Plank.

is a simple matter to replace the damaged planks and obtain, without securing special machinery, a job equally as good as when the entire surface was first laid.

Many types of bituminous pavements become objectionably brittle at low temperatures and crack or split under the loads and impacts of traffic. Asphalt planks which fall in this class do not meet the requirements of a good traffic surface. The importance of testing the strength of planks at low temperatures is therefore evident. Also some difficulties have been experienced because of asphalt plank surfaces becoming slippery in wet and icy weather. The result is that non-skid planks are demanded. To meet this demand some planks are now manufactured with small crushed stone pressed into the wearing surface. The remaining features of the planks are unaltered. These planks are generally classed as mineral-surfaced planks. (See Figure 2). Their success has not yet been determined.

Either wooden or concrete sub-floors may be used for asphalt plank surfaces. The planks are usually laid with the lengths of the sections parallel to the direction of the traffic although a few manufacturers recommend that they be placed at an angle of forty-five degrees. When placed over wooden sub-floors the planks should be laid in close contact with each other and securely spiked down with ordinary wire nails. If the sub-floor is not smooth and level, it should be put in this condition before the asphalt plank surface is applied. It is necessary that the asphalt planks possess sufficient flexibility to deform and take the contour of the sub-floor if it happens to be uneven as is often the case. When laid over concrete the planks are cemented in place with hot asphalt.

METHODS USED

Survey of Specifications

An exhaustive search through all of the leading engineering publications from 1925 to the present revealed the fact that at present there is practically no literature on asphalt plank available. It was therefore decided to study the specifications of the various manufacturers and users of the plank. Twenty-eight specifications were secured; seven were from manufacturers of the plank and the remaining twenty-one were specifications from various state highway departments and cities. It was found that several states at the present time do not use asphalt plank and consequently have no specifications for it.

An analysis of the specifications in general showed wide divergences in regard to the composition and physical properties. For example, the requirements as to composition by the different manufacturers are shown in Table I.

Even greater lack of uniformity exists in regard to the requisite physical properties and the methods of making the tests to determine them. However, in all cases except one, some specification was made concerning the following physical properties:

TABLE I

COMPOSITION REQUIREMENTS BY MANUFACTURERS OF ASPHALT PLANKS

	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7
Asphalt	35%-45%	35%-45%	28% Min.	20%-42%	45% Max.	60% Max.	40%-50%
Felt Fibre	10%-25%	10%-21%	20% Max.	4%-8%	12% Min.	10% Min.	13%-17%
Mineral	30%-50%	35%-55%	65% Max.	66%-73%	43% Approx.	25% Max.	35%-45%

Absorption	Penetration
Hardness	Toughness
Brittleness	

There were no original specifications to be found among the users of asphalt plank. Some users merely specify a certain manufacturer's plank or its equivalent while others have copied a manufacturer's specification and used that. As yet there are no standard specifications or methods of tests available for determining the suitability of asphalt planks for use as bridge floors.

Inspection Trips

Probably there is no better and more tangible criterion from which to judge the suitability of a plank than observing its performance in actual service. With this idea in mind it was decided to make inspection trips to nearby bridges on which asphalt planks are used. The object was to ascertain as much as possible about the necessary requirements of good planks and conditions which affect their service.

The first trip was taken through Pottawatomie County, Kansas. Three bridges on which asphalt planks had been laid during the fall of 1930 were inspected on this trip.

Fig. 3. Asphalt Plank Bridge Floor in Poor Condition.

Figure 3 shows the floor of the first bridge inspected. It will be observed that the floor is badly cut up. It has been in this undesirable condition since about one month after installation. The plank has also shrunk, as is shown by the wide cracks between the joints. The fact that the highway on which this bridge is located is gravelled is responsible, in part, for the poor condition of the surface. Gravel, working its way down into the cracks and lodging between the sub-floor and the planks, causes them to buckle and warp. The accumulations of gravel near the edge of the roadway and the wide cracks can be seen better in Figure 4. This surface has been subjected to heavy

Fig. 4. Failure and Buckling of Asphalt Bridge Plank Floor.

traffic, including many tractors with lugs which, together with the poor maintenance, has practically ruined the surface. The sub-floor of the bridge has been found to be in good condition.

The second bridge inspected is only a few miles north of the one discussed in the preceding paragraph. Both bridges are on the same highway. Although this floor also appeared too soft, its condition was not so bad as the

Fig. 5. Bridge Floor Laid in 1930 in Fair Condition.

first one. Figure 5 shows this surface. It was observed that where sand and gravel had been permitted to remain on the floor, buckling and cracks had begun to develop. This floor had received better maintenance than the first one. Wooden planks are kept at the bridge to be used for mutilative traffic. As a whole the floor is in a satisfactory condition and no doubt will give many years of service in the future.

The bridge spanning the Blue River at Randolph, Kansas was the third surface examined. It is shown in Figure 6. This surface was in good condition. The planks in the floor were well knitted together as a result of the traffic,

Fig. 6. Asphalt Plank Bridge Floor in Good Condition.

which fact indicates that non-mutilative traffic is highly beneficial to asphalt plank surfaces. Near the edges of the bridge roadway some sand and gravel had been permitted to collect, which as in the other cases, had caused warping and buckling of the planks in that region. Because of this condition it appears that a seal coat of asphalt would be advantageous if used near the edges of the bridge. Another type of construction which might prove satisfactory would be to use wood plank near the edges.

The bridge floor was well graded so that the elevation at mid-span was higher than that at the approaches. This is a desirable feature as with such construction there is less tendency for sand to collect on the surface than there would be if the surface were level or slightly concave. Although there was a continuous break in the surface across the bridge in line with the expansion rocker of the structure, the planks on this bridge showed evidences of unusual resistance to impact. The sub-floor appeared to be in excellent condition.

A second inspection trip was made to the bridge across the Kansas River east of Manhattan, Kansas on Highway No. 13. This bridge was surfaced during the months of October and November, 1928. The surface is of $1\frac{1}{2}$-inch planks, 8 inches in width and 6 feet in length of the brand designated as "A". A considerable amount of heavy traffic passes over this bridge, yet its surface is in excellent condition. The traffic marks which show the flexibility of the planks are evident. A picture of the surface is shown in Figure 7. This is an example of an ideal asphalt plank bridge floor. Tests results of the plank are given below the figure.

On the third and last inspection trip, the floor of the bridge a few miles west of Topeka, Kansas on Highway No. 40 was examined. This bridge is paved with 1-inch asphalt planks 8 inches wide, and 4 feet in length. The planks were laid during the winter of 1931 while the temp-

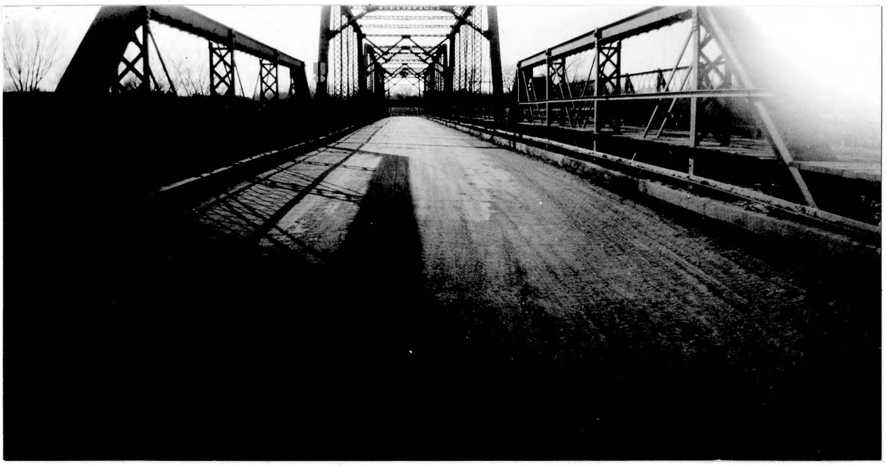


Fig. 7. Asphalt Bridge Floor Laid in 1928 in Excellent Condition.

TEST RESULTS

Percent Asphalt Filler......51.7%

Percent Fibre Filler........13.74%

Percent Mineral Filler......34.56%

Absorption Percent.......... 0.93%

Penetration Tests

A pin with 1/2 sq. inch bearing area under load of 2,000 lbs. per sq. inch.

1 minute.................... 0.33"

eratures ranged from -10° to 30° F. As it was impossible to nail the planks at these temperatures, they were heated before application by drawing them through a vat of hot water.

That the action of the traffic had not knitted the adjacent planks together is well shown in Figure 8. The reason is that the planks are very hard and brittle. Although the surface appears to be in good condition, close inspection shows that approximately one-third of the planks have cracked from the nails to the edge of the plank. A few such failures may be seen in Figure 8. Improper application undoubtedly is responsible for these failures. In some places cracks had developed across the entire surface of the bridge. It is believed that such cracks were caused by irregularities in the sub-floor or by failure of some of the planks in the sub-floor. It is also quite possible that many of the failures of the planks were caused by the planks themselves becoming loose and whipping. Figure 9 shows another view of this surface. The failure due to weaknesses in the sub-floor is apparent.

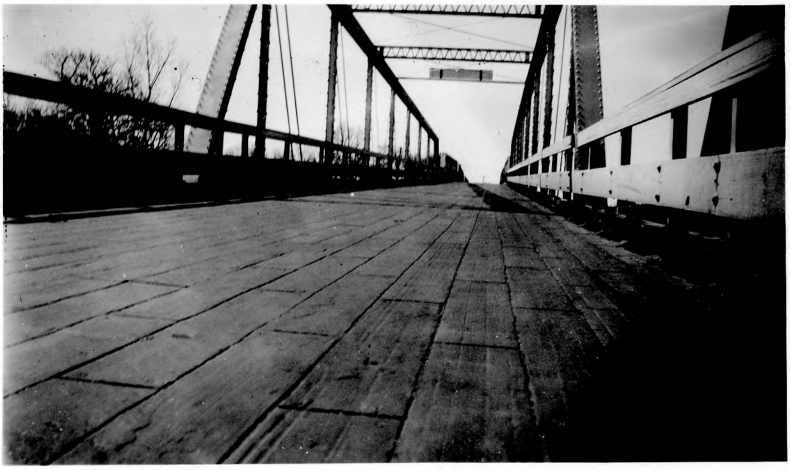


Fig. 8. Asphalt Plank Bridge Floor Showing Traffic Marks Indicating That the Planks are too Hard.

TEST RESULTS

	First Shipment	Second Shipment
Percent Asphalt......	37.0	39.3
Percent Fibre Filler.	15.5	14.7
Percent Mineral......	47.5	46.0
Percent Absorption...	1.18	0.792

Penetration Tests

A pin with 1/2 sq. inch bearing area under load of 2,000 lbs. per sq. inch.

1 minute.............	0.17"	0.17"

<u>Conclusions.</u> The important conclusions which may be drawn from the examination of asphalt plank surfaces in use are:

1. Non-mutilative traffic is highly beneficial to asphalt plank bridge surfaces as such tends to knit the adjacent planks together and thus create solid water-tight surfaces.

Fig. 9. Failure of Asphalt Bridge Plank Over Loose Sub-Floor. Note Shrinkage Cracks.

2. Mutilative traffic seriously impairs the service rendered by asphalt planks. This traffic should be prevented or minimized as asphalt planks cannot be designed to stand up under it.

3. Maintenance is an important factor. Sand and gravel should not be permitted to accumulate on the surface.

Planks should be kept tightly fastened to the sub-floor; broken and impaired planks should be replaced immediately to avoid damaging the surrounding surface.

4. It is important that the planks be properly applied. The condition of the sub-floor is a vital factor in the life of asphalt plank wearing surfaces. In the opinion of the author, application at temperatures below freezing should be prohibited.

5. It is desirable that a seal coat of asphalt be applied to those portions of an asphalt plank surface which receive little or no traffic.

Experimental Research

The experimental work consisted in making physical tests on six brands of commercial asphalt planks. The work was done in the laboratories of the Department of Applied Mechanics of the Kansas State College at Manhattan. Five brands tested were furnished by the manufacturers of the respective brands. Each furnished approximately eighteen lineal feet of each size of plank sold for highway purposes.* The planks from each source were assigned a

* The manufacturer of "C" brand sent samples of a 3/4" plank which is used for flooring of industrial buildings. The tests made on this plank were identical with the tests made on the planks used for highway purposes.

letter and all tests and reports were made by letter designation. During the surfacing of the Kansas River bridge east of Manhattan, a sample of the plank used was secured and brought to the laboratory for testing. This plank was assigned the letter "A". Brands "D" and "F" were furnished by the same manufacturer. "D" was received in July, 1932 and "F" was received in February, 1933.

The brands and sizes available for the tests were as follows:

TABLE II

BRANDS AND SIZES OF PLANKS TESTED

Brands	Thicknesses
"A"	1 1/2"
"B"	1 1/2" 1 1/4" 1"
"C"	1" 3/4" 1/2"
"D"	2" 1 1/2" 1 1/4"
"E"	1 1/2" 1"
"F"	1 1/2" 1" $1''_s$ 1/2"

Brand "F" - $1''_s$ plank was identical with the "F" - 1" plank except that it was mineral-surfaced.

In an effort to make an analysis which would reveal the essential properties of the brands it was decided to make the following determinations and tests:

Absorption

Specific Gravity

Loss on heating

Composition

Impact

Compression-shear

Penetration

Transverse-strength

Cold-brittleness

TEST PROCEDURE AND RESULTS

Preparation of Specimens

No standard method has been developed for cutting asphalt plank which is to be used for test purposes. On actual construction jobs it is cut with a hatchet, a chisel, an adz, or similar tools. Such a method is entirely unsatisfactory for laboratory purposes. Because of the plastic nature of the plank there would be "piling up" which would alter the physical properties of the specimens adjacent to the cut. The initial problem was, then the development of a satisfactory method of cutting asphalt plank for test purposes.

It was thought that the method of sawing the plank might offer some possible solution to this problem. A hand saw was tried, but no results could be obtained without swabbing the saw with kerosene at frequent intervals.

As a matter of fact it was next to impossible to cut through a plank with a common hand saw without the use of kerosene. This was due somewhat to the mineral content but mostly to the fact that the asphalt adhering to the saw caused clogging and binding. The use of kerosene would be considered satisfactory when cutting planks in the field. Because it dissolves the asphalt, its use in the laboratory must be prohibited.

Next a small motor-driven jig saw was tried. With this machine it was possible to cut the planks, but the mineral soon wore the teeth off the blades. Two blades were required to cut off a $1\frac{1}{2}$-inch plank, 8 inches wide. The saw really did not cut the plank but rather burned its way through. Since cutting with a jig saw offered no possibilities the method was abandoned.

Next an attempt was made to cut the planks with a motor-driven circular saw. The saw blade used was 8 inches in diameter and was driven at a speed of 3600 revolutions per minute. Some satisfactory results were obtained with this saw when cutting planks $\frac{1}{2}$- and 3/4-inch thick. The teeth on the saw blade wore rapidly. Planks one inch thick or thicker could not be cut by this method.

The idea was then conceived that, if the plank could be cut as pipe is cut with a pipe-cutter, satisfactory results would be obtained. With this idea in mind the blade was removed from the circular saw and placed on the milling machine as illustrated in Figure 10. The saw blade was 5/64-inch thick and the teeth, which had already been worn down and rounded, were not altered. With the machine operating at a speed of fifteen revolutions per minute

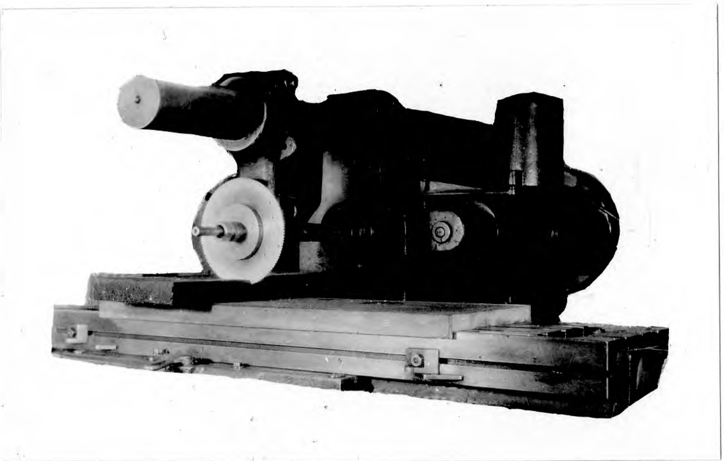


Fig. 10. Milling Machine Used in Cutting Asphalt Bridge Plank.

very satisfactory cuts were made. It was necessary to take several cuts as 1/4- or 3/8-inch is the maximum depth that can be made per cut. Heavy cast iron washers were placed on either side of the blade to prevent lateral deflection which tended to take place when making deep cuts on hard planks. The wood base was provided with guides so that it was possible to slide it back and forth on the milling machine table during the cutting process. Inspection of the ends of planks cut by this method showed that the mineral had actually been cut. There had been no tendency for the mineral to push out. This was equally true for the mineral-surfaced planks. Neither was there evidence of "piling up" or breaking of the edges. All of the specimens used for the tests of this research were cut with this machine.

Absorption

As there is no standard method of test for absorption of asphalt bridge planks, the method used was the same as that used for determining the absorption of prepared expansion joints.

Two 2"x6" specimens of each brand and thickness, with all four edges freshly cut, were cleaned and weighed to the nearest 1/4 gram. They were then immersed in a water bath and maintained at a temperature of 77° F. for 24 hours. The constant temperature bath used is illustrated in Figure 11. The temperature is kept constant by means of a thermostatically controlled electric heater. A heavy galvanized two-mesh screen wire in the bottom of the bath, on which the specimens rest, permits their entire surfaces to be in contact with the water at all times. At the end of the 24-hour period the specimens were removed, wiped

Fig. 11. Electrically Controlled Constant Temperature Bath.

off with a slightly dampened cloth, and weighed again. The weight before immersion subtracted from the weight after immersion was taken as the absorption. The percent of absorption was computed by dividing the gain in weight by the weight before absorption. The average of the percentages of absorption of the two specimens was taken as the percent of absorption.

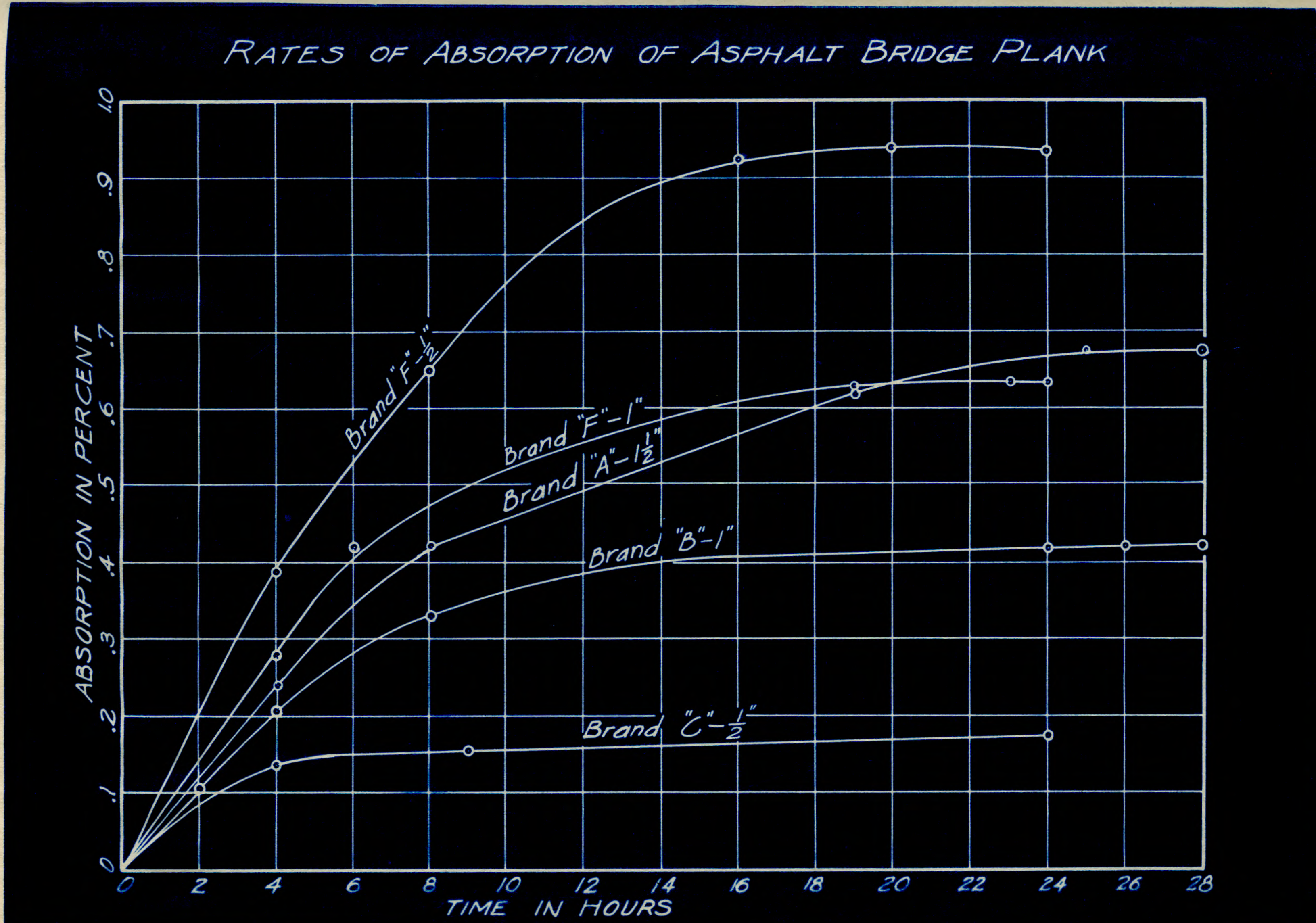
Tests were also run on some of the brands to determine the rates of absorption. It was thought that such information would be valuable and would also serve as a check on the 24-hour period of immersion. Curves showing the rates of absorption are shown in Figure 12.

Figure 13 shows a graph of the percents of absorption for the various brands and sizes of planks tested. It will be observed that the absorption in all cases is small, but there is no consistency between the absorption of the different sizes of the same brands.

Absorption is usually considered a rough measure of the durability of a material.

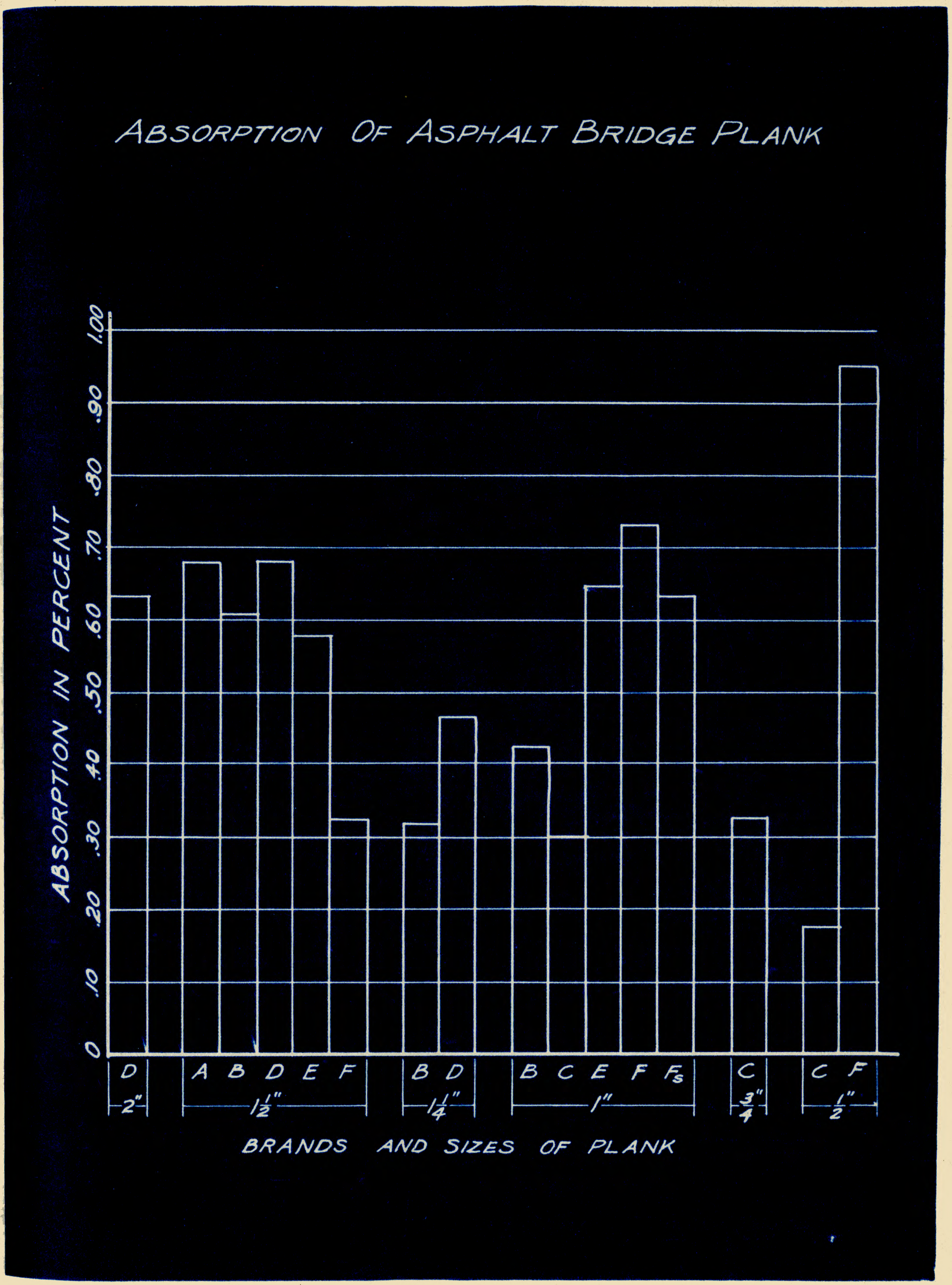
Specific Gravity

Specific gravity is the ratio of the weight of a material to the weight of an equal volume of water. It does not represent any particular quality, but is often specified in order to control uniformity of product. Specific gravity is of importance for bridge pavements because it is desirable to keep the dead weight of the bridge as low as possible. As the specific gravity of the flooring increases so does the cost of the structure increase. Planks of high specific gravities a re thus undesirable as they do not possess the advantage of lightness of weight.



RATES OF ABSORPTION OF ASPHALT BRIDGE PLANK
ABSORPTION IN PERCENT
TIME IN HOURS
Brand "F"-1/2"
Brand "F"-1"
Brand "A"-1 1/2"
Brand "B"-1"
Brand "C"-1/2"
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28

Fig. 12



ABSORPTION OF ASPHALT BRIDGE PLANK
ABSORPTION IN PERCENT
0
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
D
2"
A B D E F
1½"
B D
1¼"
B C E F Fs
1"
C
¾"
C F
½"
BRANDS AND SIZES OF PLANK

Fig. 13

The apparatus used for this test was an analytical balance. Two specimens of each brand and thickness of plank were weighed in air to the nearest 1/4 gram. They were then weighed immersed in water at 77° F. Before weighing them in water, all adhering air bubbles were removed. The specific gravity was then computed from the following formula:

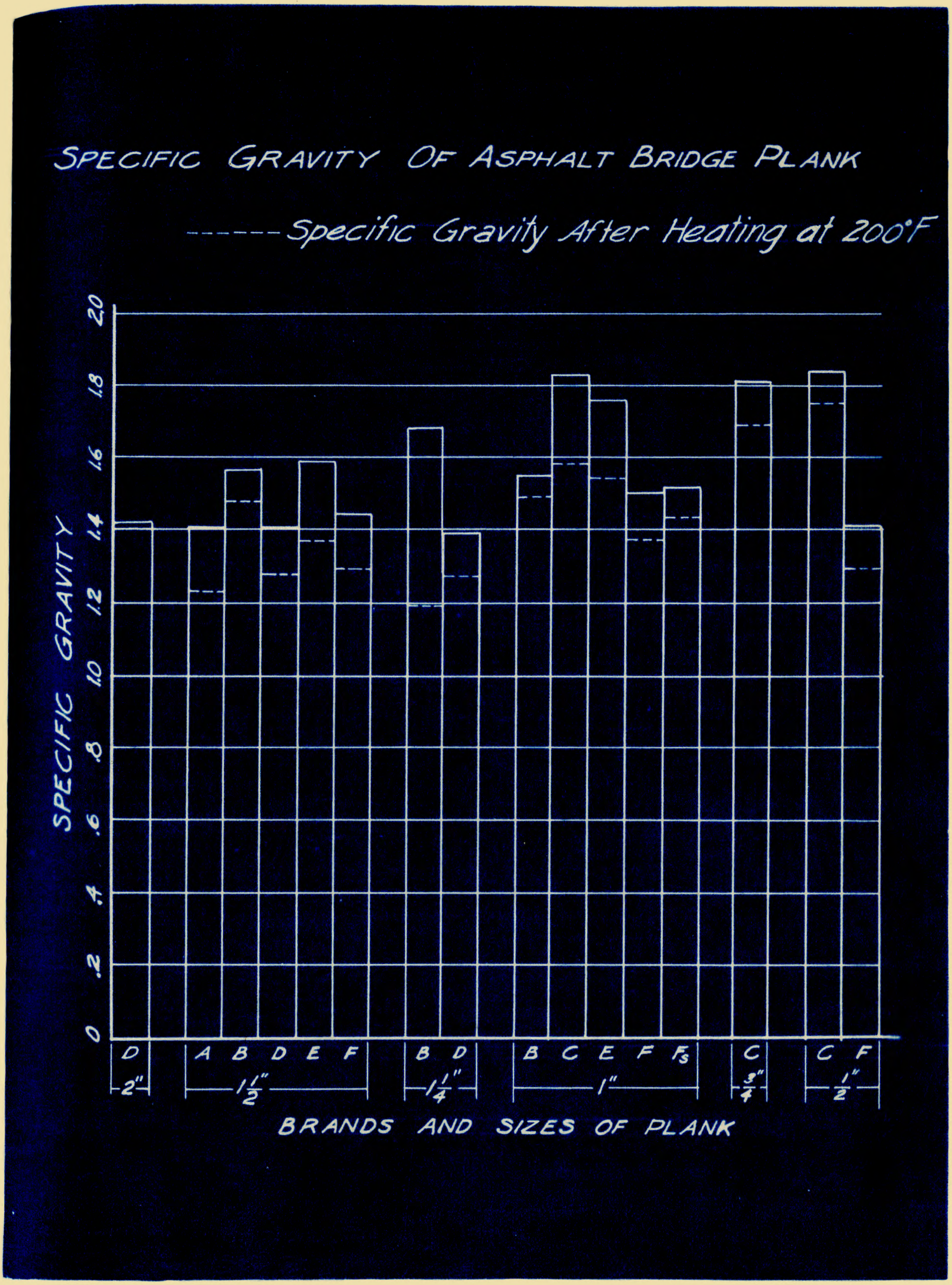
$$\text{Specific Gravity} = \frac{W_a}{W_a - W_w}$$

where W_a = weight in air

and W_w = weight in water.

The average of the results secured from each two samples was used. These averages are shown graphically in Figure 14. The dotted lines show the specific gravities after the specimens had been heated at 200° F. for 20 hours.

It will be observed that the variation in specific gravities is from 1.39 to 1.84, corresponding to values of 86.7 and 115 pounds per cubic foot respectively. Although there is some lack of uniformity, the weights per cubic foot of the different sizes of each brand are about the same.



SPECIFIC GRAVITY OF ASPHALT BRIDGE PLANK
------Specific Gravity After Heating at 200°F
SPECIFIC GRAVITY
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
D
2"
A B D E F
1 1/2"
B D
1 1/4"
B C E F F5
1"
C
3/4"
C F
1/2"
BRANDS AND SIZES OF PLANK

Fig. 14

Loss On Heating

This test is also known as the volatization test. One specimen of each brand and size of plank was heated in an air oven at 200° F. for 20 hours. Before placing the specimens in the oven they were weighed to the nearest 1/4 gram. At the end of the 20-hour period the specimens were removed and allowed to cool to room temperature. They were then weighed again and the percents of loss computed. It was found that upon keeping the specimens in the oven for another 20 hours no additional losses occurred.

The results of these tests are presented in Figure 15. A decided change in volume took place when some of the brands were subjected to this test. The specimens did not shrink to their original volumes when cooled to room temperature. Figure 16 shows the changes in volume that occurred. The same specimens were next cooled to -25° F. and kept at this temperature for 20 hours at the end of which time they were removed, allowed to warm to room temperature, and their specific gravities again determined. It was found that they had not shrunk as a result of the cooling. Specimens which had not been subjected to the loss on heating test showed no permanent shrinkage upon similar cooling.

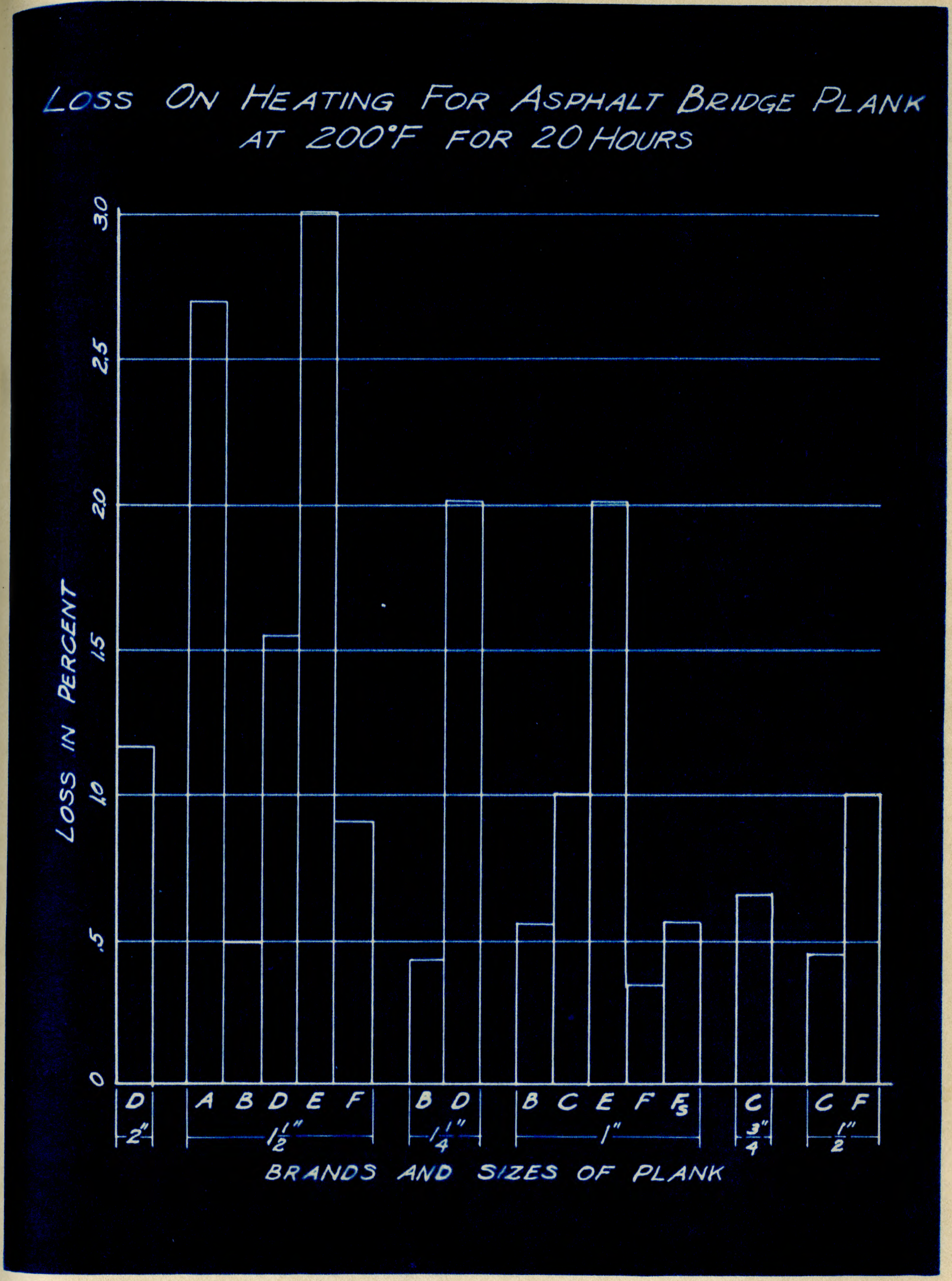
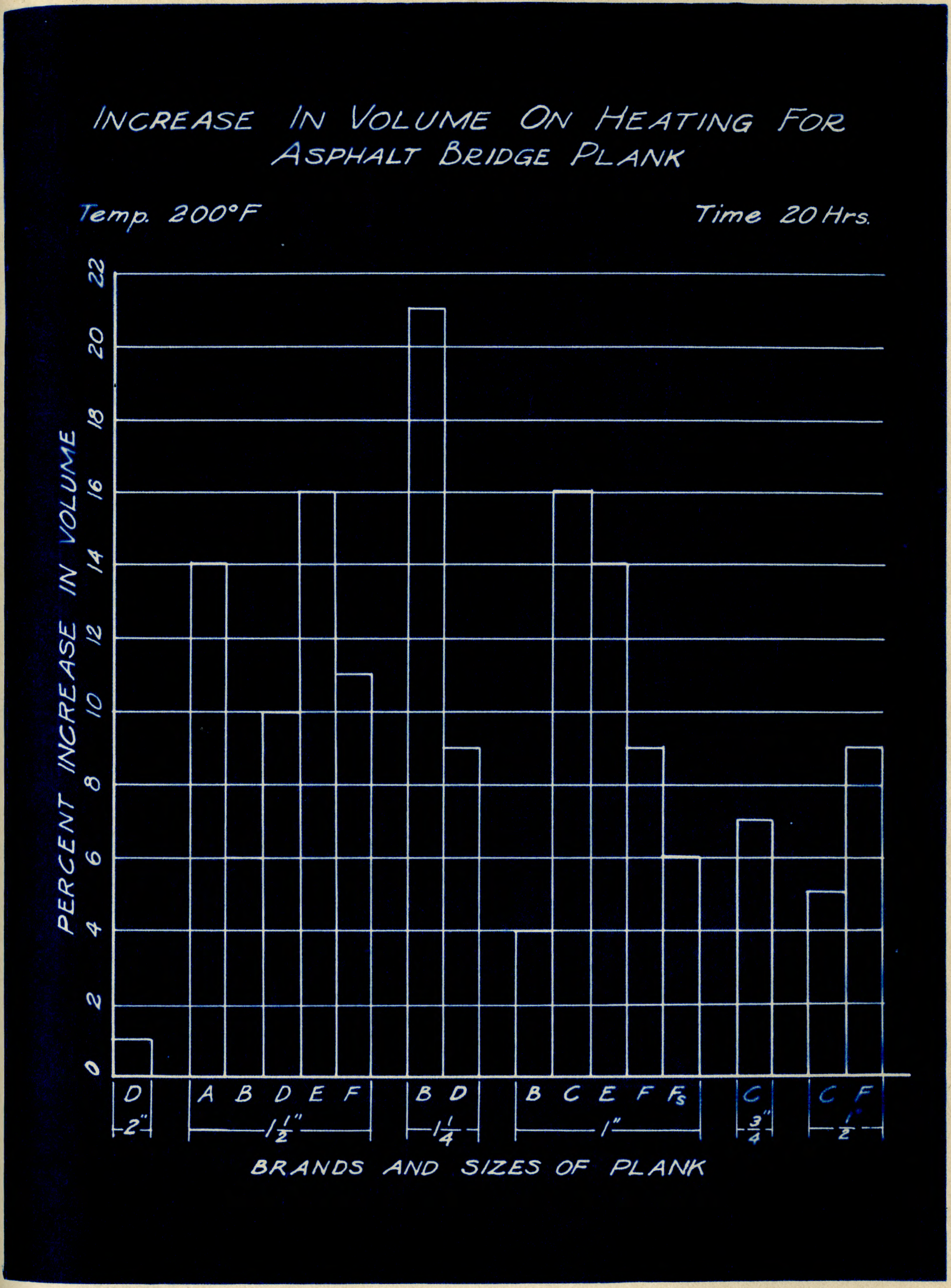

LOSS ON HEATING FOR ASPHALT BRIDGE PLANK
AT 200°F FOR 20 HOURS
LOSS IN PERCENT
0
.5
1.0
1.5
2.0
2.5
3.0
D
A B D E F
B D
B C E F F_S
C
C F
2"
1 1/2"
1 1/4"
1"
3/4"
1/2"
BRANDS AND SIZES OF PLANK

Fig. 15



INCREASE IN VOLUME ON HEATING FOR ASPHALT BRIDGE PLANK
Temp. 200°F
Time 20 Hrs.
PERCENT INCREASE IN VOLUME
0
2
4
6
8
10
12
14
16
18
20
22
D
2"
A B D E F
1 1/2"
B D
1 1/4
B C E F Fs
1"
C
3/4"
C F
1/2
BRANDS AND SIZES OF PLANK

Fig. 16

Absorption tests on samples which had been subjected to the loss on heating test showed that there was no change in absorption resulting from this test. In other words, the absorption was the same after heating as it was before heating.

Composition

The percentage of asphalt in each case was determined by taking the average of the results secured from two one-hundred gram samples. Carbon tetrachloride was added and the mixture allowed to sit until all lumps were dissolved and reduced to a soft consistency. The bitumen was extracted with a Rotarex machine. The bitumen-free residue was then dried to a constant weight in the air oven which was maintained at a temperature of 200° F. The weight of the residue subtracted from the original weight of the sample was taken as the percent of bitumen.

The residue of the one-hundred gram sample, after extraction of the asphalt as described above, was used in determining the percent of fibre. The residue was ignited to a constant weight, and the loss in weight was considered the amount of fibre present. The weight of ash which remained after determination of the felt was taken as mineral.

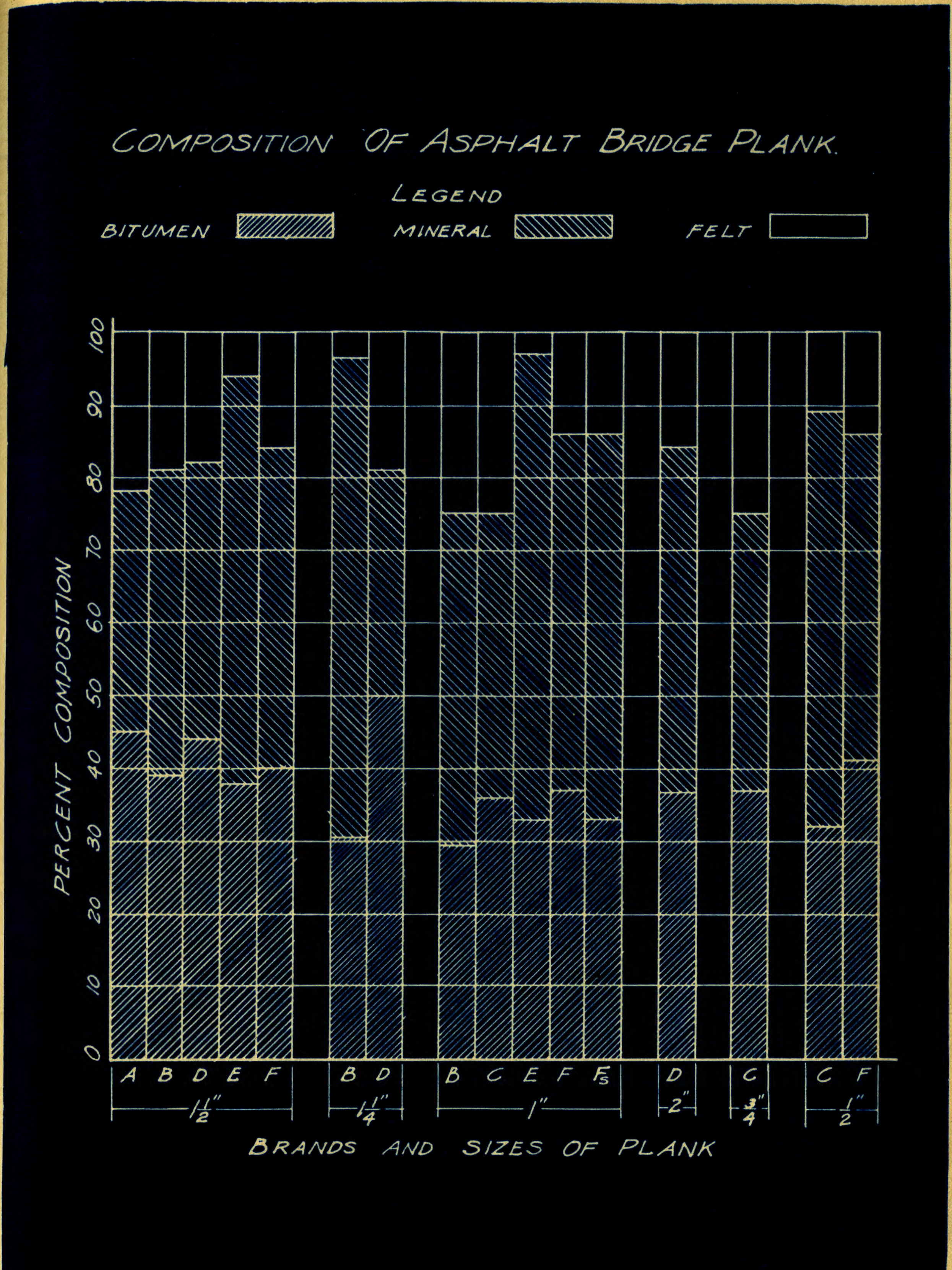
Composition determinations were also made, using samples other than one hundred grams. Practically the same results were obtained in all cases. The temperature at which the felt should be burned off is questionable as there is possibility of driving off part of the carbon dioxide contained in the limestone aggregate. This problem, however, is now under investigation by members of the staff of the Department of Applied Mechanics.

The graph of Figure 17 shows the various compositions as obtained from this test. Very wide variations are apparent.

Impact

The impact test furnishes a means of measuring the ability of a plank to resist shock. It is a measure of the toughness. The machine used for making this test was an Olsen 120-foot pound-capacity machine of the pendulum type. It is illustrated in Figure 18. The samples tested were 6 inches long and the widths used varied with the thickness as follows:

Thickness	Width	Thickness	Width
1/2"	6"	1 1/4"	4"
3/4"	6"	1 1/2"	3"
1"	6"	2"	2"



COMPOSITION OF ASPHALT BRIDGE PLANK.
LEGEND
BITUMEN
MINERAL
FELT
PERCENT COMPOSITION
0
10
20
30
40
50
60
70
80
90
100
A B D E F
1 1/2"
B D
1 1/4"
B C E F F5
1"
D
2"
C
3/4"
C F
1/2"
BRANDS AND SIZES OF PLANK

Fig. 17

Fig. 18. Machine for Making Impact Tests.

Five specimens of each brand and thickness* were tested. The specimens were immersed in the water bath and kept at a temperature of 77° F. for 24 hours. They were then removed and each specimen firmly clamped in the impact machine at H with the grain vertical. The pendulum

---

* No impact tests were made on "D" - 2" plank because the machine would not accommodate 2-inch plank.

G was then raised until the pointer could be set at 60 on the scale I. It was next released and the reading taken on the scale. The broken specimen was then removed from the machine. The readings taken were subtracted from 60 to get the impact absorbed in breaking the specimens and the average was taken for each group. Marked variations were observed between the amounts of energy absorbed in breaking different samples of the same brand and size. In some cases this variation was as great as 10 foot pounds. It was thought that this variation might have been due to inaccuracy in cutting the specimens. Consequently the widths of all of the broken specimens were measured and found to vary as much as 1/4-inch in a few cases. However, the results showed that there was no relation between the variation in the width of the sample and the impact absorbed up to this amount. It is evident, then, that the planks tested lacked uniformity.

Because experience has shown that some asphalt planks become brittle and are easily cracked and split in cold weather, the impact tests were also run on specimens cooled to 32° F. These tests were run in a manner similar to the one described above. The specimens were cooled in the constant temperature bath which was filled with a mixture of cracked ice and water. Specimens for this test were kept in the bath for 6 hours prior to making the tests.

The results of the impact tests are shown in Figure 19.

Compression-Shear

The compression-shear test is an indicator of the resistance of the material to displacement. The method used in making this test followed quite closely the recommendations of the Philip Carey Company. A 200,000-pound Olsen screw machine, counterpoised so as to have a maximum capacity of 10,000 pounds, was used for making the tests. With this arrangement it was possible to read loads to the nearest pound. The machine was provided with a special three-inch spherical top bearing attached to the moving head. A flat-faced, machined steel plunger, 6 inches long, with a cross-section 2"x2" was also provided. A constant temperature bath was constructed by soldering heavy galvanized iron, three inches in height, to a 9"x9" steel plate 1/2-inch thick. By means of a plate and a suitable adjustable upright provision was made for attaching the Federal indicating dial, which was used to measure the deformations. Figure 20 shows the apparatus set up for this test.

The specimens tested were 6"x6". Four tests were made on each brand and size of plank; two at 77° F. and two at

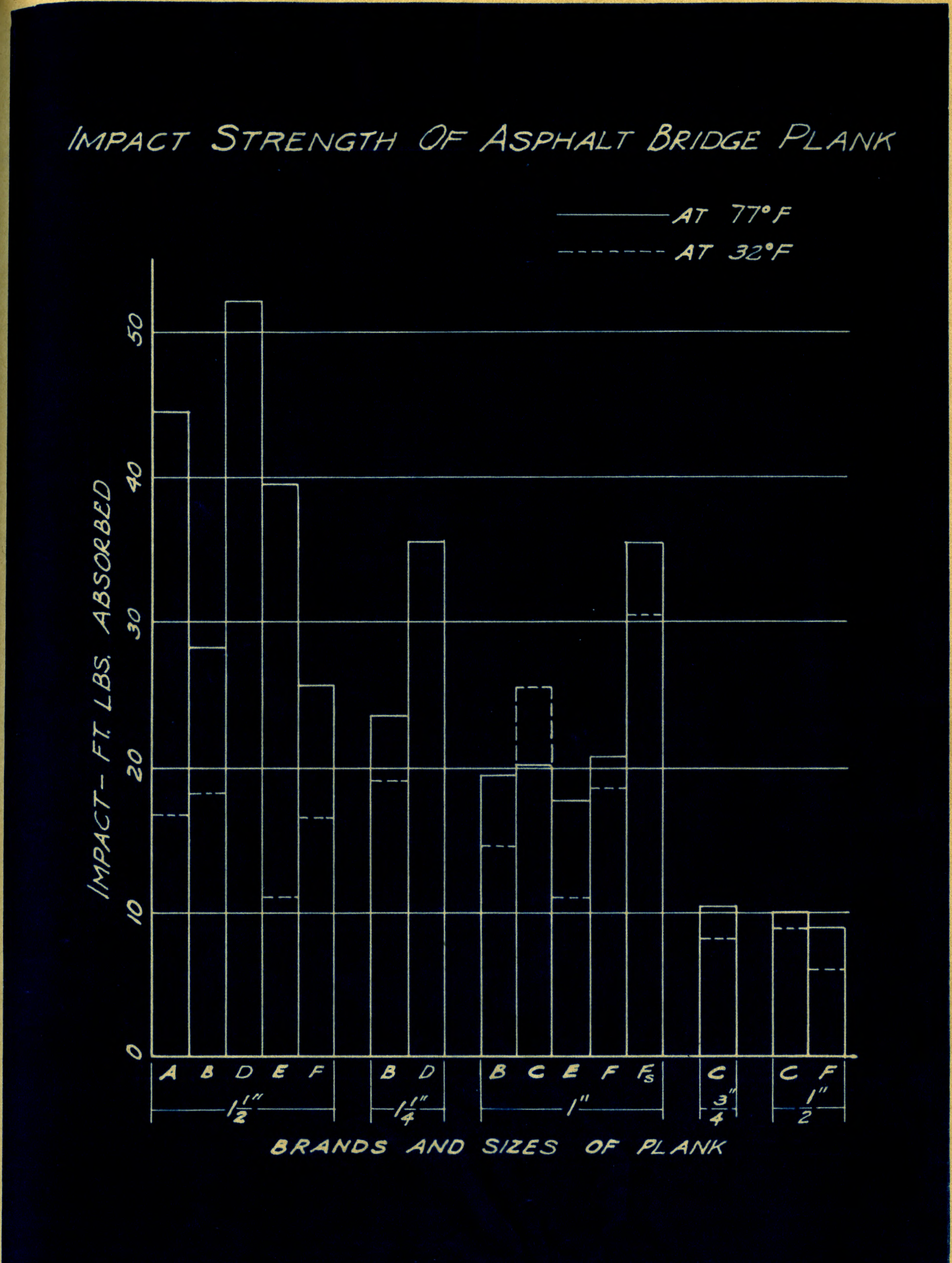

IMPACT STRENGTH OF ASPHALT BRIDGE PLANK
AT 77°F
AT 32°F
IMPACT - FT. LBS. ABSORBED
0
10
20
30
40
50
A B D E F
B D
B C E F F_s
C
C F
$1\frac{1}{2}''$
$1\frac{1}{4}''$
1"
$\frac{3}{4}''$
$\frac{1}{2}''$
BRANDS AND SIZES OF PLANK

Fig. 19

135° F. Each specimen was immersed in the water bath (Figure 11) at the required temperature for 5 hours. It was then placed in the center of the bottom of the portable bath. The steel plunger was placed in the center of the specimen and the head of the testing machine was run down until the balancing beam, previously set at zero, touched the upper bar of the beam-gate. The dial was then set at

Fig. 20. Compression-Shear Test.

zero, the poise set at the required load and the head moved down at a speed of 0.05" per minute until the beam was balanced. At 77° F. the first load used was 1400 pounds (350 pounds per square inch). This load was kept constant for a period of 10 minutes. The dial was then read to determine the deformation of the specimen. The poise of the machine was next set at 2800 pounds (700 pounds per square inch) and the head again moved down at the rate of 0.05" per minute until the beam was balanced. This load was also kept constant for 10 minutes and the dial again read. Dial readings were recorded in fractions of an inch.

Loads of 400 pounds and 1400 pounds (100 and 350 pounds per square inch respectively) were applied in making the test at 135° F. These loads were maintained constant for periods of 5 minutes. It was necessary to heat the stationary platen of the testing machine and cover the bath to avoid an excessive temperature drop while making the tests at 135° F.

The curves of Figure 21 and Figure 22 show the rate of deformation for one brand of plank at 77° F. Figure 21 is for the load of 350 pounds per square inch and Figure 22 is for the load of 700 pounds per square inch. Further investigation indicated that all brands gave approximately the same curves. It will be observed that for planks thicker than one inch the deformation increases rapidly with an increase in the length of time which the load is maintained. The one-inch planks hold loads quite well for long periods of time.

Figure 23 and Figure 24 give graphically the deformation resulting from the compression-shear tests. Figure 2, page 11, shows some specimens which have been subjected

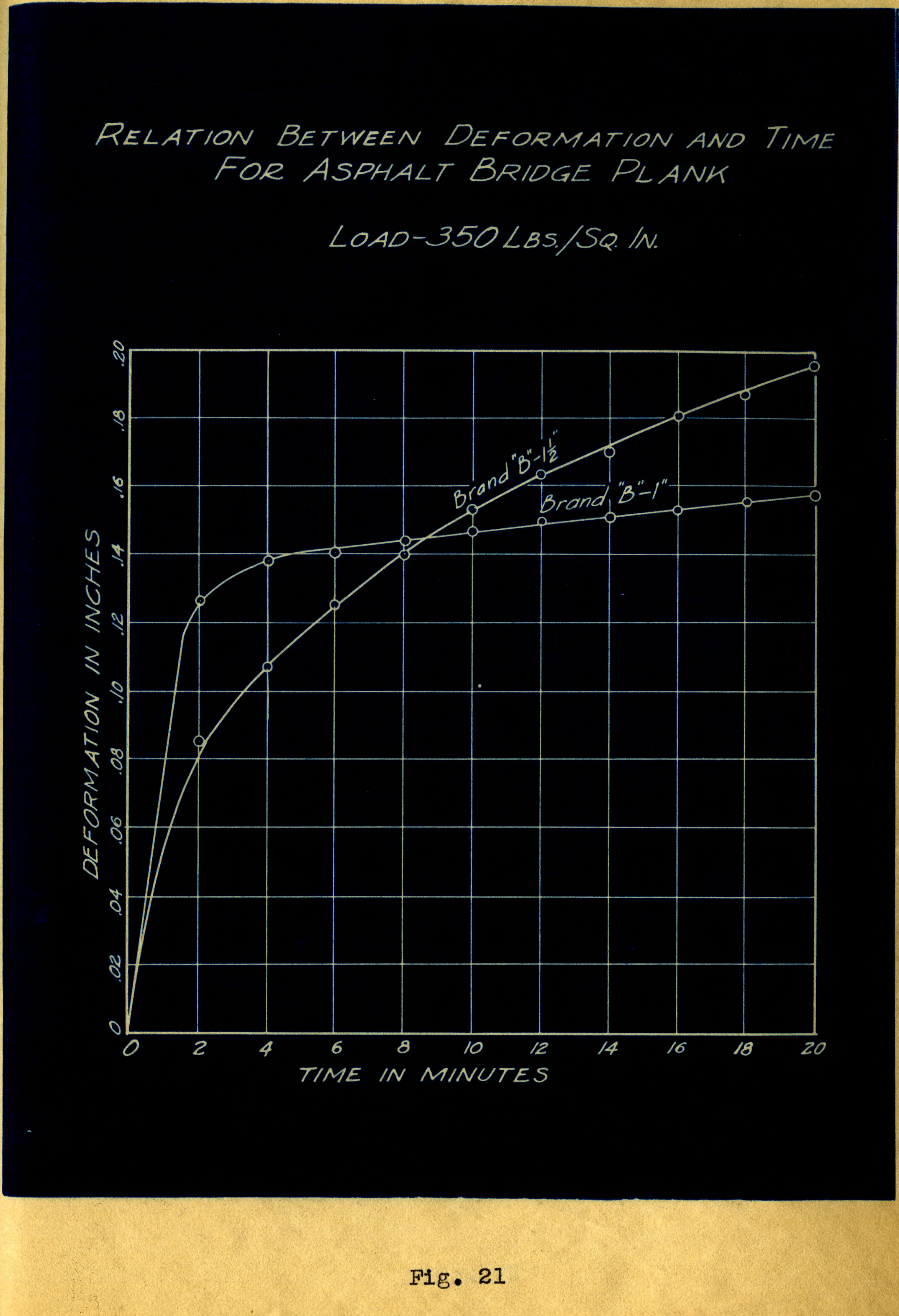

RELATION BETWEEN DEFORMATION AND TIME
FOR ASPHALT BRIDGE PLANK
LOAD-350 LBS./SQ. IN.
DEFORMATION IN INCHES
0
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
TIME IN MINUTES
0
2
4
6
8
10
12
14
16
18
20
Brand "B"-1½"
Brand "B"-1"

Fig. 21

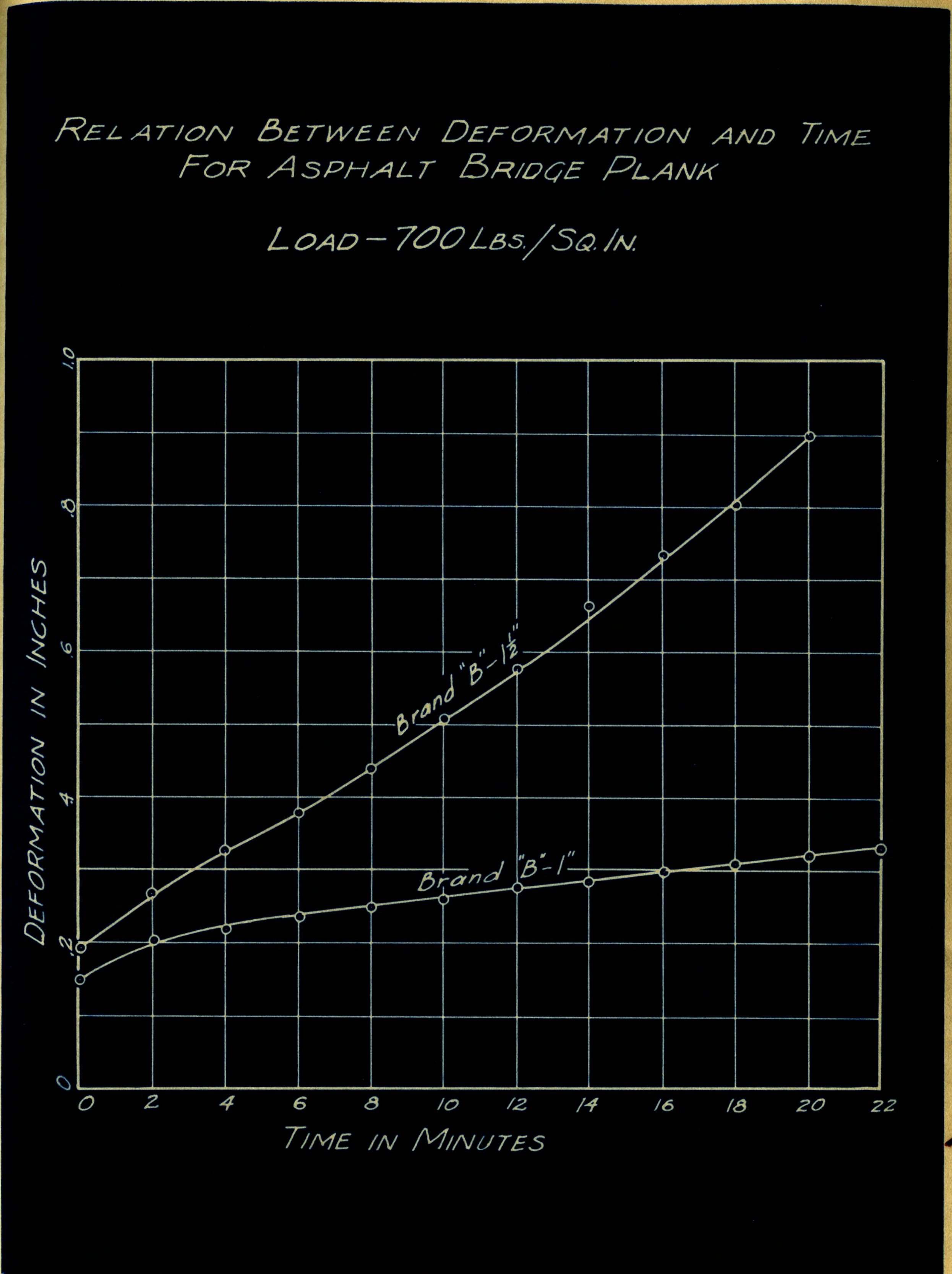

RELATION BETWEEN DEFORMATION AND TIME
FOR ASPHALT BRIDGE PLANK
LOAD – 700 LBS./SQ. IN.
DEFORMATION IN INCHES
0
.2
.4
.6
.8
1.0
0
2
4
6
8
10
12
14
16
18
20
22
TIME IN MINUTES
Brand "B" – 1½"
Brand "B" – 1"

Fig. 22

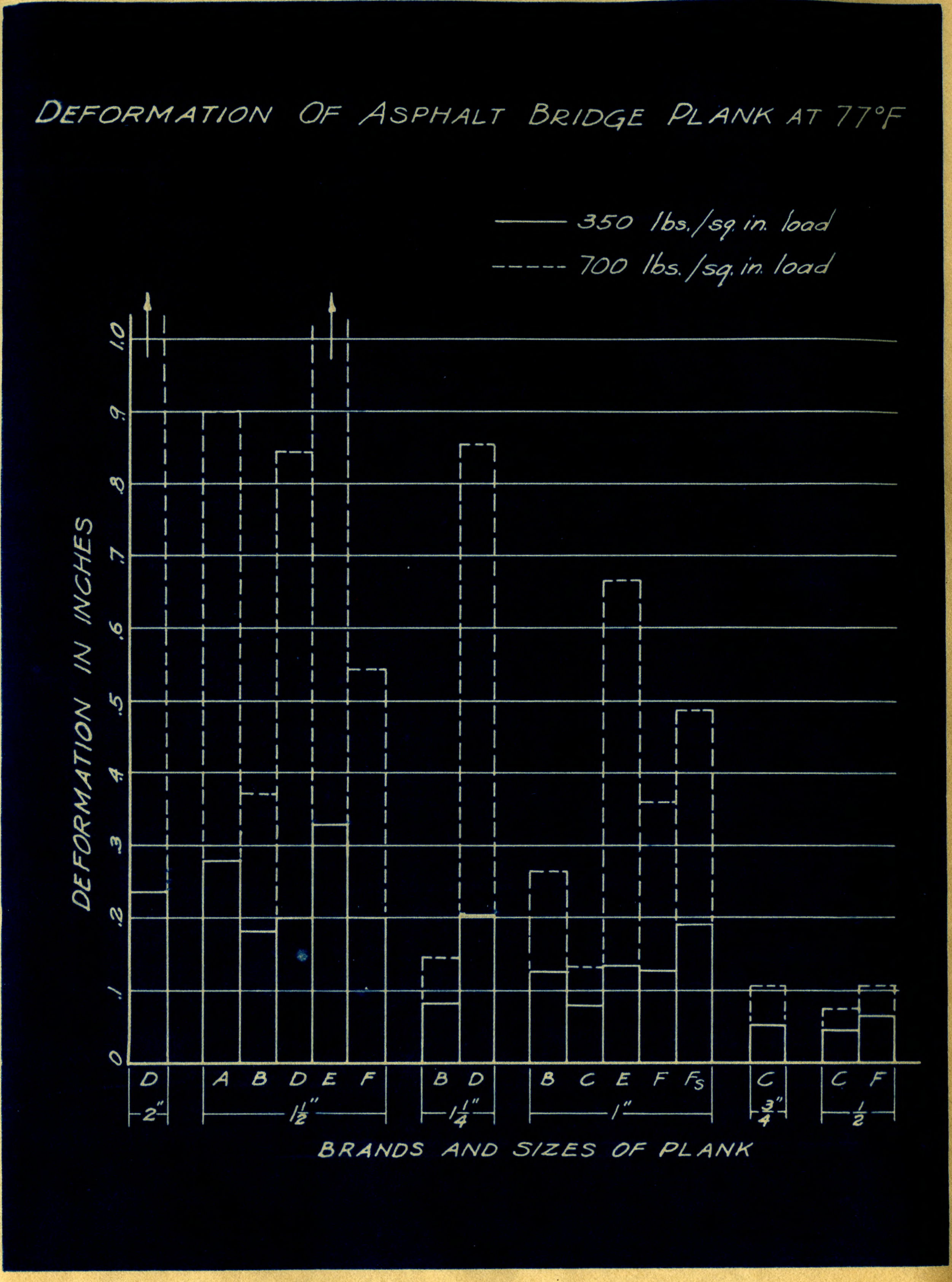

DEFORMATION OF ASPHALT BRIDGE PLANK AT 77°F
350 lbs./sq. in. load
700 lbs./sq. in. load
DEFORMATION IN INCHES
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
D
A B D E F
B D
B C E F Fs
C
C F
2"
1½"
1¼"
1"
¾"
½
BRANDS AND SIZES OF PLANK

Fig. 23

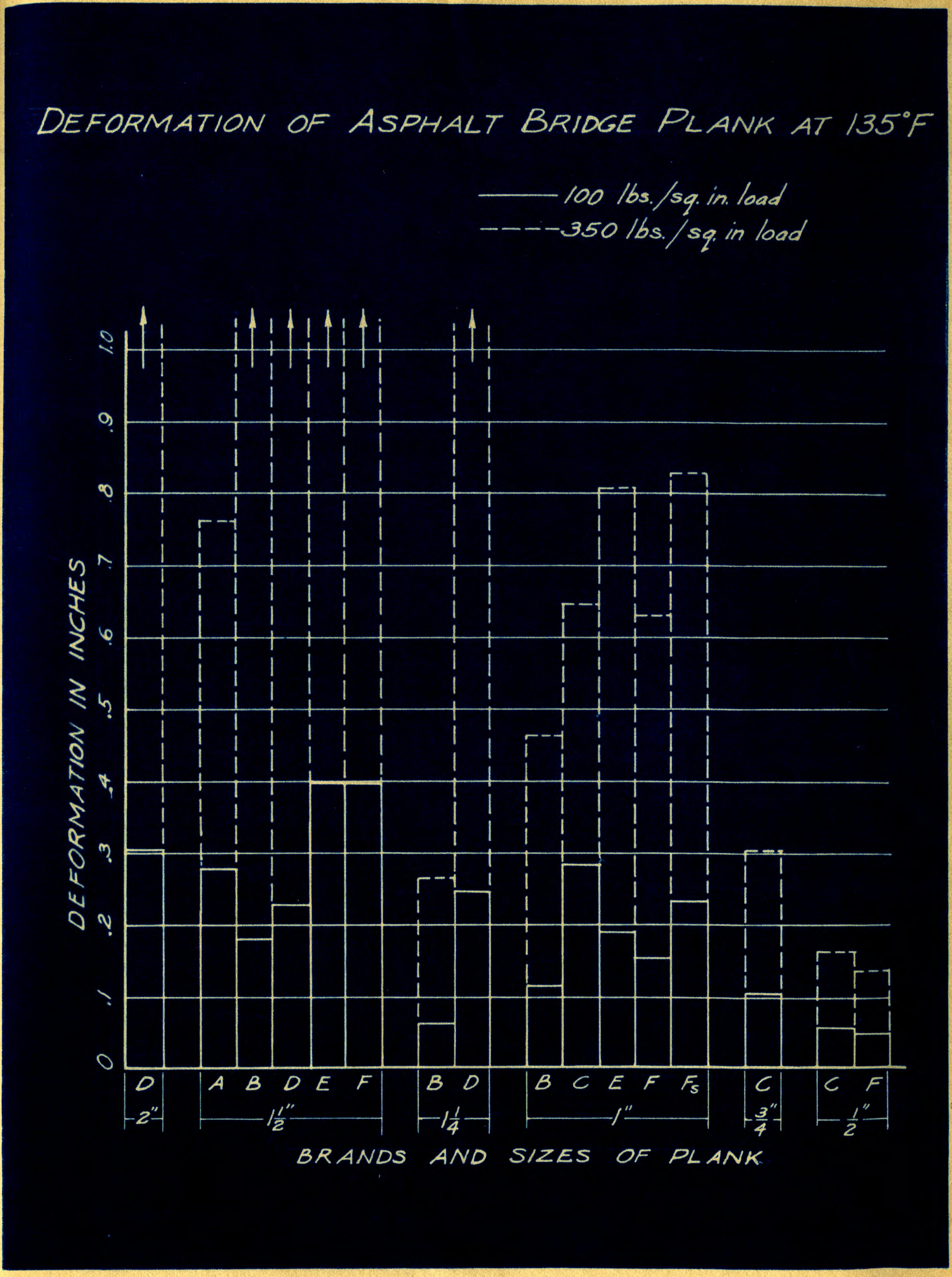

DEFORMATION OF ASPHALT BRIDGE PLANK AT 135°F
——— 100 lbs./sq. in. load
- - - - 350 lbs./sq. in load
DEFORMATION IN INCHES
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
D
A B D E F
B D
B C E F Fs
C
C F
2"
1 1/2"
1 1/4
1"
3/4"
1/2"
BRANDS AND SIZES OF PLANK

Fig. 24

to the compression-shear test.

Compression-shear tests made on specimens at 32° F. gave the following results:

TABLE III

RESULTS OF COMPRESSION-SHEAR TESTS AT 32° F.

Brand	Size	Deformations in inches at 32° F.		
		350 lbs. per sq.in.	700 lbs. per sq.in.	1000 lbs. per sq.in.
E	$1\frac{1}{2}$"	.020	.095	.247*
B	$1\frac{1}{4}$"	.002	.019	.050
C	1"	.044	.054	.068

* Split under the 1000 pounds per square inch load.

Penetration

The penetration tests were made in an attempt to measure the surface hardness of the various brands. The apparatus used was a New York Testing Laboratory penetrometer with a cylindrical plunger 1/4-inch in diameter bearing a total load of 2225 grams. Five 2"x2" specimens of each brand and thickness were tested. These tests were made at 135° F. Two sets of tests were made; one on specimens which had been kept in the constant temperature bath for one hour and the other, on specimens which had been

Fig. 25. New York Penetrometer Adapted for Penetration Tests.

allowed to remain in the bath for a period of 24 hours.

After the specimen had been in the bath the required length of time, it was placed in the glass dish (See Figure 25) in which there was sufficient water at 135° F. to cover it completely. The plunger was then brought in contact with the surface of the specimen. The foot of the rack was brought in contact with the top of the plunger shaft and the dial read. Next the plunger was released and the dial read again at the end of one minute. The difference between the first and last readings was taken as the penetration in tenths of millimeters. The average was taken of the 5 specimens tested.

Care was used, while making these tests, to prevent grease or other material from coming in contact with the needle, for any such matter on the needle would vitiate the results.

In testing the mineral-surfaced specimens the penetrations were taken on the surface containing the stone. The plunger was always placed between the stones, however.

Results of these tests are given in Figure 26. There is some indication that the penetrations after the 24-hour immersions are greater than those taken after the one hour immersion. Further investigations along this line, however, show that the length of the period of immersion makes little difference as long as it is one hour or more.

Transverse-Strength

The transverse-strength tests were made to determine the flexural strengths of the brands in pounds per square inch. The stress in the extreme fibres at the breaking point is termed the modulus of rupture. In as much as experience has shown that difficulties due to planks cracking and breaking nearly always occur at low temperatures,

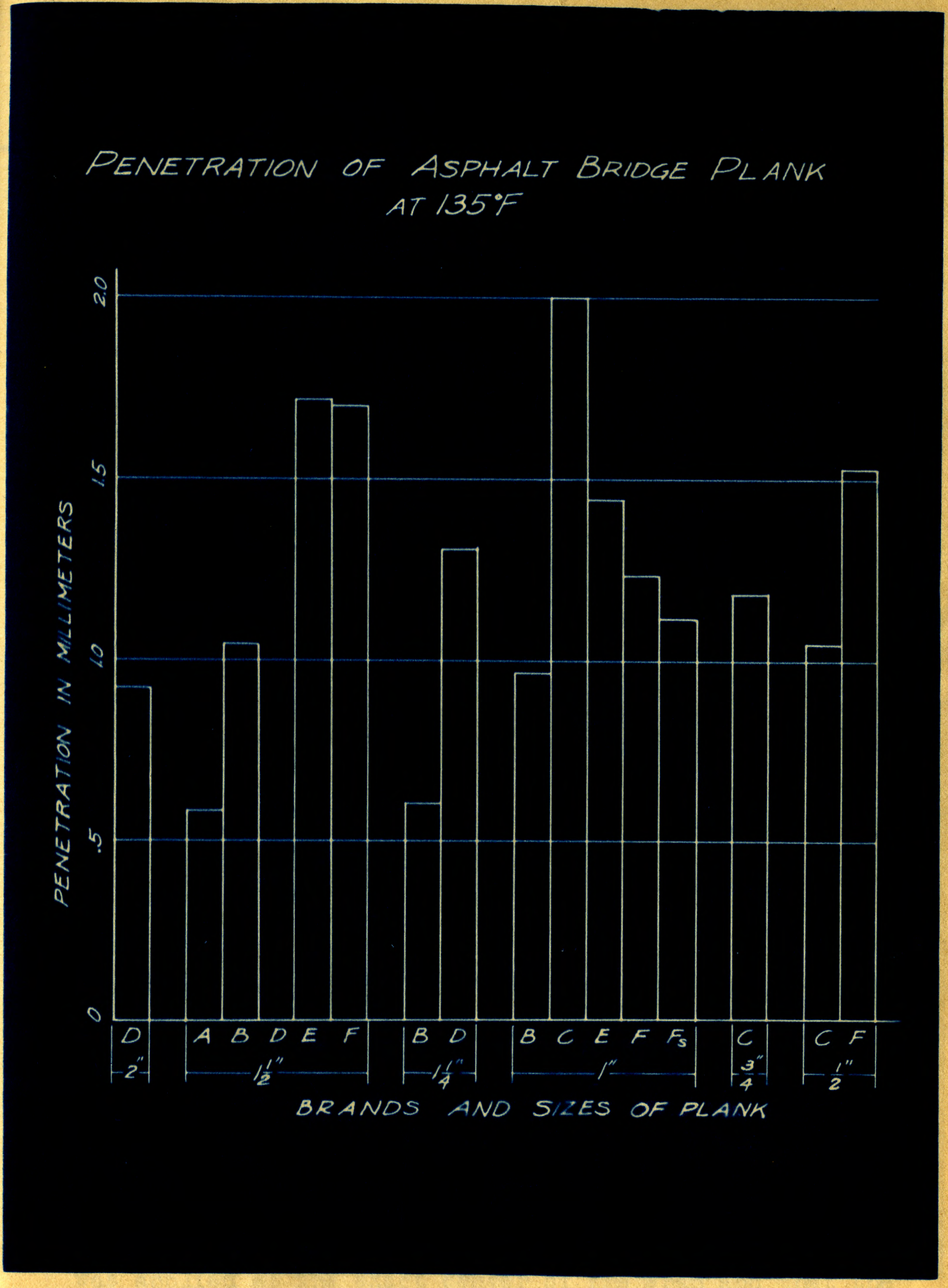

PENETRATION OF ASPHALT BRIDGE PLANK
AT 135°F
PENETRATION IN MILLIMETERS
2.0
1.5
1.0
.5
0
D
2"
A B D E F
1½"
B D
1¼"
B C E F F_s
1"
C
¾"
C F
½"
BRANDS AND SIZES OF PLANK

Fig. 26

these tests were made on specimens at 32° F. The ability of planks to deflect under load is important. Especially is this true when they are placed over wooden sub-floors. For this reason deflections at the breaking points were taken while making the transverse-strength tests.

Two 2"x6" specimens of each brand and thickness were tested on the Olsen 200,000 pound machine after they had been immersed in an ice and water bath at 32° F. for 5 hours. The machine was counterpoised so as to give it a maximum capacity of 10,000 pounds. Readings could be made to the nearest pound.

The method of making the test is illustrated in Figure 27. A special adjustable support was made so that the length of clear span used in each case was three times the nominal thickness of the sample. The Federal indicating dial was used for taking the deflections. The load was applied at the rate of 0.05" per minute, and the beam of the testing machine was kept balanced until failure of the specimen. The indicating dial was set to zero with the beam balanced under no load. It was then read at the time the specimen failed, which reading was the maximum deflection in inches. Care was taken to see that the load was applied at the exact center of the span and that the dial was placed directly below the point of application

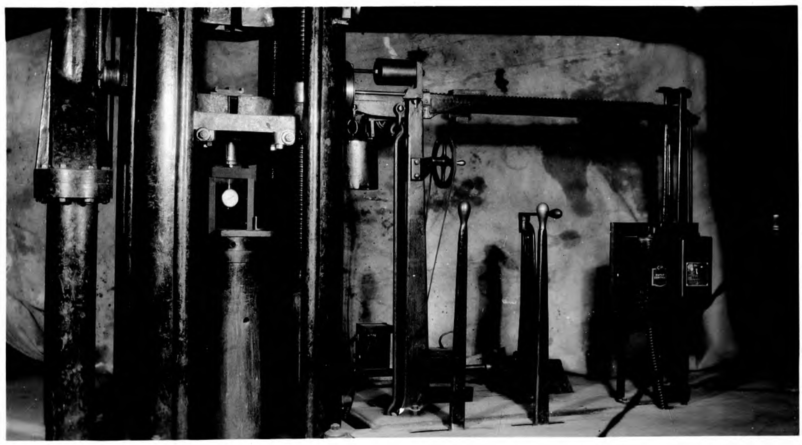


Fig. 27. Beam Test for Determining Maximum Fibre Stress and Deflection.

of the load.

The formula used for calculating the modulus of rupture was developed as follows:

M = maximum bending moment in inch pounds.

P = load at failure of specimen in pounds.

L = length of span in inches.

b = width of cross-section of specimen in inches.

d = depth of cross-section of specimen in inches.

c = distance from centroidal axis of cross-section to extreme fibre in inches.

I = moment of inertia of cross-section about the centroidal axis.

S = modulus of rupture in pounds per square inch.

$$M = \frac{PL}{4}$$

$$S = \frac{MC}{I}$$

$$I = \frac{bd^3}{12}$$

$$C = \frac{b}{2}$$

$$S = \frac{3PL}{2bd^2}$$

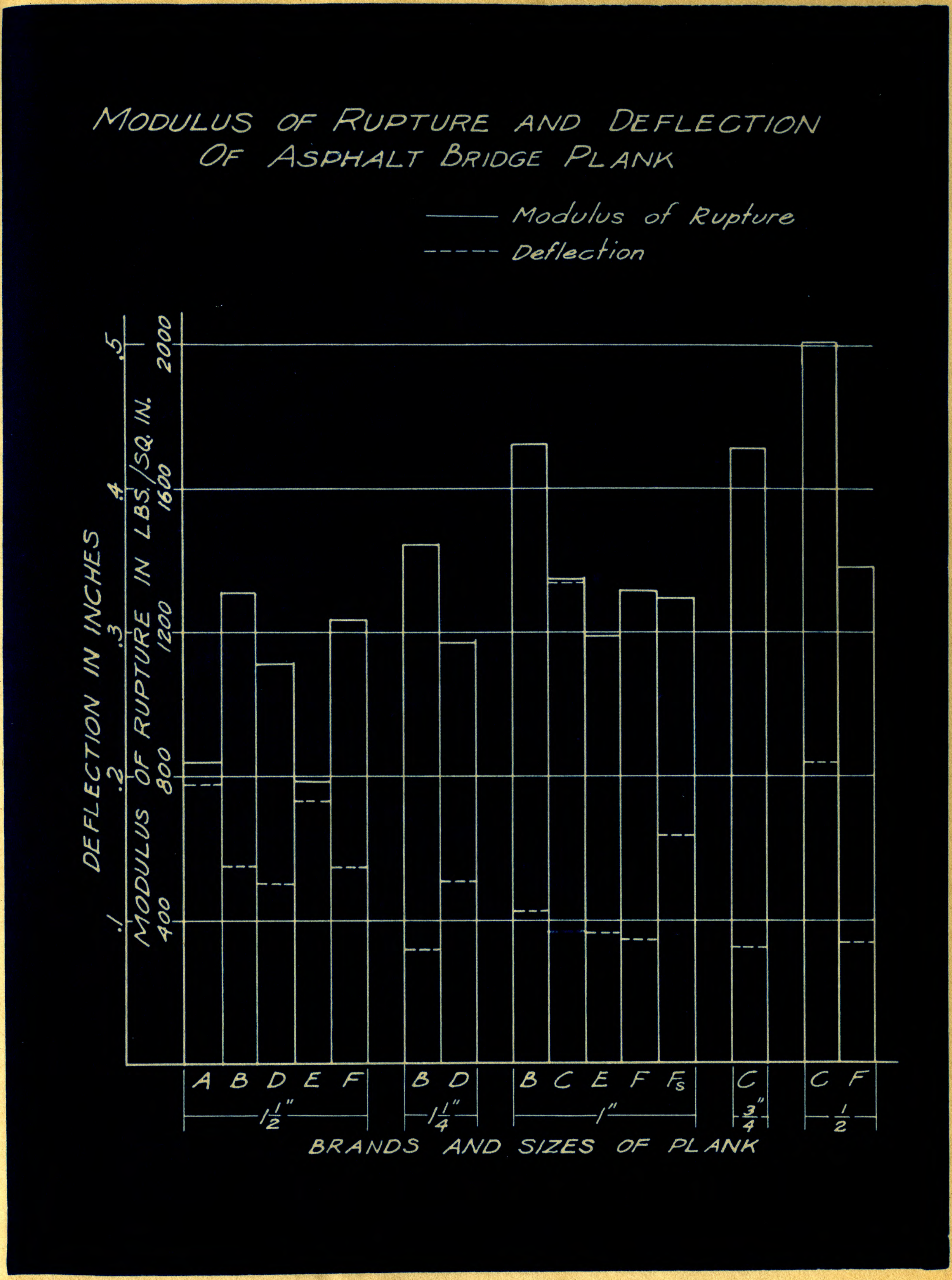
The cross-sections of all specimens were measured with a steel scale to the nearest .01". This was necessary as it was impossible to cut out the specimens so that they were exactly 2 inches wide.

Results of this test are shown in Figure 28.

Cold-Brittleness

This test has a very definite and self-evident value. As it frequently becomes necessary to handle asphalt planks under various extremes of weather and climate, planks should be capable of being nailed and used at freezing temperatures without danger of cracking or breaking.

The specimens used were 6"x6" and two of each brand and size were tested. They were first placed in a bath containing a mixture of cracked ice and water and maintained at 32° F. for 5 hours. A 30-penny nail was then driven



MODULUS OF RUPTURE AND DEFLECTION OF ASPHALT BRIDGE PLANK
Modulus of Rupture
Deflection
DEFLECTION IN INCHES
MODULUS OF RUPTURE IN LBS./SQ. IN.
.1
.2
.3
.4
.5
400
800
1200
1600
2000
A B D E F
$1\frac{1}{2}''$
B D
$1\frac{1}{4}''$
B C E F F_S
1''
C
$\frac{3}{4}''$
C F
$\frac{1}{2}$
BRANDS AND SIZES OF PLANK

Fig. 28

through the corners of each specimen $1\frac{1}{2}$-inch from each edge. During the driving process the specimens were supported on a soft timber block 2 inches thick and approximately 8"x12". The nails were driven through the asphalt plank specimens to a depth of approximately one inch in the timber block.

Because the human equation is so great when the nails are driven with a hammer, it was decided to develop a nail-driving machine with which to make these tests. This machine consisted of a fourteen-pound cylindrical weight which was dropped from certain heights through a hollow cylindrical tube which served as a guide. (See Figure 29). The heights of drop were so selected for each thickness that the nails were driven through the specimens with one blow. Very satisfactory results were obtained with this simple machine.

The results of these tests were recorded in percent, 100% if all nails were driven without cracking the specimen and 0% if the four nails cracked or split it at each corner. At the left in Figure 2, page 11, are shown two specimens which have failed the nail driving test. "E" is an example of a 0% passable while "F" is 75% passable.

The results of the cold-brittleness tests are given in Table IV with the complete summary of the test results.

TABLE IV

SUMMARY OF DATA

Sample	Size	Specific Gravity	Percent Absorption	Percent Loss on Heating	Percent Increase in Volume on Heating at 200° F.	Percent Felt	Percent Bitumen	Percent Mineral	Impact, Ft.Lbs. Absorbed at 77°F.	Impact, Ft.Lbs. Absorbed at 32°F.	Penetration in Tenths MM. 135° F. 1 min.	Compression-Shear Deformation: 350 lbs. per sq. in.77°F. 10 min.	700 lbs. per sq. in.77°F. 10 min.	100 lbs. per sq. in.135°F. 5 min.	350 lbs. per sq. in.135°F. 5 min.	Cold Brittleness Percent Passable	Modulus of Rupture lbs. per sq.in.	Deflection in inches
D	2"	1.41	.631	1.16	1	16	37	47	---	---	9.6	.236	.986*	.180	.948	25	---	---
A	1½"	1.41	.678	2.70	14	21.4	45	33.6	44.5	16.7	5.8	.277	.900	.273	.760	100	843	.1950
B	1½"	1.57	.608	.48	6	19.0	39	42.0	28.2	18.2	10.4	.180	.370	.179	.955	75	1315	.1375
D	1½"	1.41	.679	1.54	10	18.0	44	38.0	52.2	---	10.8	.197	.844	.225	.928*	75	1152	.1250
E	1½"	1.59	.577	3.02	16	6.0	38	56.0	39.5	11.0	17.2	.327	.991*	.395	.970*	0	787	.1835
F	1½"	1.44	.326	.77	11	16.0	40	44.0	26.2	17.0	17.0	.199	.542	.396	.800*	0	1237	.1360
B	1¼"	1.68	.319	.43	41	3.6	30.4	66.0	23.6	19.0	6.0	.080	.145	.071	.263	0	1441	.0810
D	1¼"	1.39	.464	2.16	9	19.0	50.0	31.0	33.5	---	13.0	.203	.856	.244	.974*	75	1174	.1275
B	1"	1.55	.423	.56	4	24.4	29.3	46.3	19.6	14.5	9.6	.124	.264	.112	.462	50	1720	.1075
C	1"	1.83	.302	1.01	16	25.0	36.0	39.0	20.2	25.7	20.0	.077	.130	.281	.643	100	1374	.3250
E	1"	1.76	.643	2.19	14	8.0	33.0	61.0	17.7	11.0	14.4	.132	.666	.188	.805	0	1191	.0925
F	1"	1.50	.730	.34	9	14.0	37.0	49.0	20.7	18.7	12.3	.127	.356	.151	.626	0	1316	.0865
F_s	1"	1.52	.630	.58	6	14.0	33.0	53.0	35.5	30.5	11.1	.186	.487	.228	.822	75	1298	.1600
C	3/4"	1.81	.325	.66	7	25	37	38	10.3	8.2	11.8	.051	.104	.105	.303	25	1712	.0825
C	½"	1.84	.175	.44	5	11	32	57	10	9	10.4	.044	.071	.053	.162	100	2084	.2100
F	½"	1.41	.948	1.03	9	14	41	45	9	6.3	15.3	.061	.107	.049	.135	100	1382	.0850

* This deformation occurred in less than 5 minutes as the specimens would not take the load.

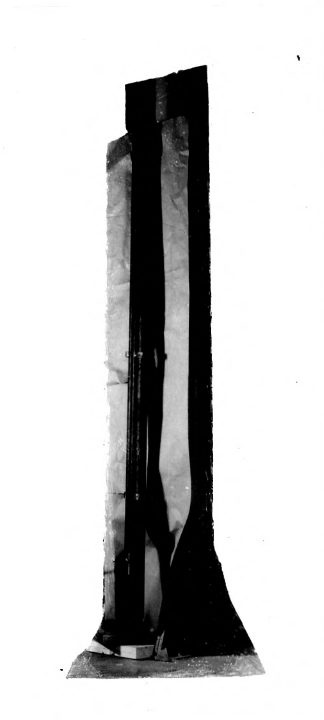


Fig. 29. Machine for Driving Nails in the Cold-Brittleness Tests.

DISCUSSION AND CONCLUSIONS

The data of this investigation are summarized in Table IV. Wide variations in the physical characteristics are apparent, which render it difficult to draw definite conclusions.

The specific gravities vary from 1.39 to 1.84 but are quite uniform for different sizes of the same brand of plank. This test appears to be relatively unimportant.

Of course the suitability of planks decreases with increases of specific gravities, as it is desirable that the planks be as light as possible. In the opinion of the author 1.8 should be the maximum allowable.

The absorption of all of the brands was small, being less than 1% in every case. This indicates that the asphalt planks as now manufactured do not absorb enough moisture to be of any consequence. It appears however that 1% should be the maximum permitted.

The losses on heating in all cases were small and were not uniform for a single brand of plank. It is believed that the wearing qualities of the planks bear some relation to the loss on heating. In the opinion of the author planks showing values in excess of 3% for this test should not be accepted. For most of the planks studied during this research these losses were relatively unimportant.

The fact that the brands increased in volume upon heating and failed to shrink to their original volumes when subsequently cooled shows that asphalt planks do not shrink. If laid in close contact they will remain so permanently regardless of seasonal changes and weather conditions.

Planks of widely varying compositions were tested, as is evident from the data. Within the ranges tested there was no definite relation between the composition of the plank and their physical properties. It appears from this fact that tests based on composition only are of little value in judging the suitability of asphalt plank for use as bridge floors.

There is no relation between the results of the impact test at 77° F. and those at 32° F. In one case ("C"-1") a higher value was obtained at 32° F. than at 77° F. The author makes no attempt to explain this condition. Table V shows the results of the impact tests in foot pounds of energy absorbed per square inch of cross-sectional area.

Table V shows that thicker planks are more resistant to shock than thinner planks at a temperature of 77° F. It is interesting to note, however, that the resistance at 32° F. is about the same for all sizes of planks.

No relation exists between the results of the penetration tests and those of the compression-shear tests. This indicates that tests of surface hardness (penetration tests) should not be accepted as a measure of the ability of planks to resist displacement or to support heavy loads.

There is no consistent relation between the transverse strength and the deflection. It was thought that there would be a definite relation between the deflection and the

TABLE V

IMPACT ABSORBED
PER SQUARE INCH OF CROSS-SECTIONAL AREA

Brand	Size	Ft.Lbs. Abs.at 77° F. 1 sq.in.	Ft.Lbs. Abs.at 32° F. 1 sq.in.	Brand	Size	Ft.Lbs. Abs.at 77° F. 1 sq.in.	Ft.Lbs. Abs.at 32° F. 1 sq. in.
A	$1\frac{1}{2}$"	9.90	3.70	B	1"	3.26	2.41
B	$1\frac{1}{2}$"	6.27	4.05	C	1"	3.37	4.30
D	$1\frac{1}{2}$"	11.60	---	E	1"	2.95	1.84
E	$1\frac{1}{2}$"	8.80	2.44	F	1"	3.45	3.12
F	$1\frac{1}{2}$"	5.80	3.78	F_s	1"	5.92	5.10
B	$1\frac{1}{4}$"	4.72	3.80	C	3/4"	2.29	1.82
D	$1\frac{1}{4}$"	6.70	---	C	$\frac{1}{2}$"	3.33	3.00
				F	$\frac{1}{2}$"	3.00	2.08

impact test as these two tests attempt to measure similar properties of the materials. It was found, however, that no relation exists between the transverse-strength tests and the impact tests or between the deflection and the impact values.

The fact that the fibre stresses for the thin planks were in some cases greater than those for thick ones might explain why thin planks give better service in some cases than thick planks.

Although the need of a cold-brittleness test is fully recognized, it is doubtful whether the one as carried out in this study measures the desired property of the plank. It was found in the laboratory that specimens, through which nails had been driven when heated to 135° F., showed no tendency to crack on subsequent cooling to -25° F. When struck with a hammer cracking and failures occurred where struck and not necessarily in the vicinity of the nails. The author believes that the impact tests at 32° F. and the transverse-strength tests are more informative tests.

As there is no definite relation between the composition and the physical properties, or between any of the individual physical properties, it is believed that specifications should be based on a series of suitable physical tests. In the opinion of the author the following tests are significant and should be made to determine the suitability of asphalt planks for use as bridge flooring:

Composition	Transverse-strength
Compression-shear	Impact
Cold-brittleness	

These tests as carried out in the laboratory appear to be quite satisfactory with the exception of cold-brittleness test. However, until a better test can be developed, it is recommended that this test be made. In view of the fact that a number of planks now in use are known to be rendering satisfactory service, it is impossible to set close limits on these tests in drawing up specifications. The results of the above tests on planks now on the market will cover a wide range. The following limits are recommended:

Felt - 10%-25%	Modulus of rupture - 1000 lbs. per sq. in. min.
Bitumen - 30%-50%	Deflection - 0.10 in. minimum.
Mineral - 35%-55%	Cold-brittleness - 100% passable.

COMPRESSION-SHEAR - DEFORMATION

	$\frac{1}{2}$" and 3/4"	1" and $1\frac{1}{4}$"	$1\frac{1}{2}$" and 2"
At 77° F., 10 min. 350# / sq. in.	.05" - .10"	.10" - .20"	.10" -.30"
700# / sq. in.	.05" - .10"	.20" - .50"	.30" -.90"
At 135° F., 5 min. 100# / sq. in.	.05" - .10"	.10" - .25"	.10" -.30"
350# / sq. in.	.10" - .20"	.25" - .75"	.30" -.90"

IMPACT - FOOT POUNDS ABSORBED

Thickness of Plank	Minimum Impact Value in Ft. Lbs. At 77° F.	At 32° F.
$\frac{1}{2}$"	9	6
3/4"	10	8
1"	20	12
$1\frac{1}{4}$"	25	16
$1\frac{1}{2}$"	35	18

Different thicknesses of the same brand of planks showed considerable variation in composition and physical properties, which also may explain why thin planks give better service than thicker ones in some cases.

In the opinion of the author engineers are not justified in using the Philip Carey specifications, as they are not adapted to the asphalt planks that are now being manufactured. This conclusion has been reached because many of the commercial planks which are giving satisfactory service will not pass these specifications.

Certain brands of planks are no doubt better suited for service in warm climates than in cold climates and vice versa. Results of the impact, compression-shear, cold-brittleness, and transverse-strength tests show this fact.

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