THE EFFECT OF IRON WHEELED CARTS ON FLEXIBLE AND RIGID HIGHWAY PAVEMENTS

By

Ali Avni Kirkagaclioglu
Bachelor of Science
Rolla School of Mines and Metallurgy
Rolla, Missouri
1951

Submitted to the Faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE
1952

THE EFFECT OF IRON WHEELED CARTS ON FLEXIBLE AND RIGID HIGHWAY PAVEMENTS

ALI AVNI KIRKAGACLIOGLU

MASTER OF SCIENCE

1952

THESIS AND ABSTRACT APPROVED:

J. Rogers Martin
Thesis Adviser

Faculty Representative

D. C. McIntosh
Dean of the Graduate School

Acknowledgement

Upon finishing the last requirement of his present program of study for the Degree of Master of Science in Civil Engineering, the writer wishes to acknowledge his indebtedness to the following individuals who have helped him attain his present status in the field of Civil Engineering.

To Professor J. Rogers Martin, his thesis adviser, for his many valuable ideas and suggestions and for working personally with him in the laboratories.

To Miss Jerry Clendenin for her excellent work in the typing, arranging and checking of this thesis.

Ali Kirkağaçlioğlu

Ali Avni Kirkagaclioglu

Summer 1951
Stillwater, Oklahoma

Table of Contents

Figures

Tables

THE PROBLEM AND ITS SCOPE

Turkey in Asia Minor, about 1,000 miles long from east to west and about 300 miles wide, is a little larger than Texas.[1] It became a republic in 1923. With one-eighth of the population and one-tenth of the area of the United States, it has all-weather roads aggregating less than 1% of the mileage of similar roads in the United States. It has a population of 21,000,000, about 50 people per square mile as compared with 44 people per square mile in the United States.

Predominantly it is an agricultural nation. As lack of adequate highway facilities is no reflection on the ability of the Turkish nation to visualize and determine transportation needs, the first objective in transportation was to finance and build a network of 6,900 kilometers of railroad to handle mass transport. In the short space of 23 years this was accomplished except for a few extensions to be added in due course.

The determination of the Turkish nation to proceed in fulfilling its highway needs in an orderly manner is both rational and timely. In such a country of relatively short distances, in modern terms, highways can be built, bettered, and maintained at low cost. Increased mobility is an economic necessity; expensive animal transportation can no longer be afforded. Agricultural and industrial developments must not be retarded by lack of modern highway transportation. Fertile land too far removed from railroads to make products marketable, should be brought into agricultural production by tapping these regions with farm-to-market highways. Improved highway transportation will make it possible for farmers to grow wider varieties of products, marketable in new trade centers farther from home, and thus will reduce the risk in-

---

[1] H. E. Hilts,"Highway Planning in Turkey", <u>Proceedings ASCE</u>, February, 1951.

volved in relying on a single crop. Losses in weight of livestock caused by driving the animals to market could be conserved by trucking, as in the United States. Just as in the case of agriculture, improvements would result in all economic fields - mining, manufacturing, and fishing - as markets and sources of the products are brought closer together by better transportation.

Another ruling factor is that the terrain is unusually difficult. The approaches to the Anatolian Plateau, at an elevation of about 3,000 ft above sea level, have made railroad location difficult and costs high.

The 1947 rural road mileage of Turkey was estimated as 41,800 km. This total is divided into a proposed national system of 20,000 km and 21,800 km of provincial roads. There are also about 100,000 km of city and village streets and other rural roads. Although 11,000 km are classified as having macadam surfaces, inspections have shown that the roads are deficient in width and are not structurally sound enough to carry the increasing motor traffic. Likewise most of the bridges are deficient in both width and strength. These conditions lend themselves to revisions of both line and grade on practically all the main routes of the system.

Total motor vehicles registration in Turkey in 1947 was 12,913 of which two-thirds represented trucks and busses. In 1947 traffic counts showed that vehicles were distributed as follows:

TABLE 1

Type	%
Animal Drawn	70.7
Passenger Automobiles	10.9
Trucks	18.4
	100.0

The total traffic per day exceeded 1,000 vehicles at only seven stations out of 190, whereas the total motor traffic exceeded 500 vehicles per day at only five stations.

As Table 1 shows, 70.7% of the traffic is animal drawn, iron wheeled coaches or two wheeled carriages.

The Public Roads Administration of Turkey is just starting to surface the old or newly constructed macadam roads with the new methods which the United States is using. Although this problem does not exist in the United States, other parts of the world must face the problems of iron wheeled, horse drawn vehicles. The Public Roads Administration of Turkey has heretofore done nothing concerning this problem. At this stage of highway construction, which is the initial step in a ten year program, the effects of narrow iron wheel loads must be taken into consideration and the different pavements in different locations of the country be designed accordingly.

Problems of iron wheel loads vary. These are:

1. Contact area is very small when compared with the pneumatic tire. This is an important factor in designing the thickness of the pavement.

2. Deformation of the flexible pavement under the sharp edged iron wheel.

3. Contact of two hard surfaces (rim and concrete mat) and its effect on the joints of rigid pavements.

The purpose of this report is to design satisfactory flexible and rigid pavements and compare them, making actual laboratory tests under the worst conditions. This report also describes the physical features of the test, the testing equipment and also presents the results.

Vertical deformation of the pavement, caused by the passage of a simulated iron wheel load was obtained after each 50 cycles of loading. From these data pass-strain curves were drawn for each flexible pavement. For rigid pavements special kinds of joints were constructed to support the worst conditions and t he results were merely observed (not measured) after 500 and 1000 cycles.

The characteristics of materials used either were determined or were already known. They were given in the test procedures.

The primary purpose of this report is the design of flexible pavements having high internal friction which can withstand severe conditions without yielding and shearing.

The secondary objective was perfection of the technique of operating the laboratory roller, which had never been used prior to this project.

To make a good comparison, two bituminous concrete pavements and four cement concrete expansion joints were made and tested in the laboratory under the heaviest load of 2000 lbs (500 lbs per wheel), smallest diameter of wheel of 36 inches, and the smallest width of 2 inches. Thus the conditions imposed corresponded to the worst conditions which may be expected in practice.

FIGURE-1

Profile of the outfit

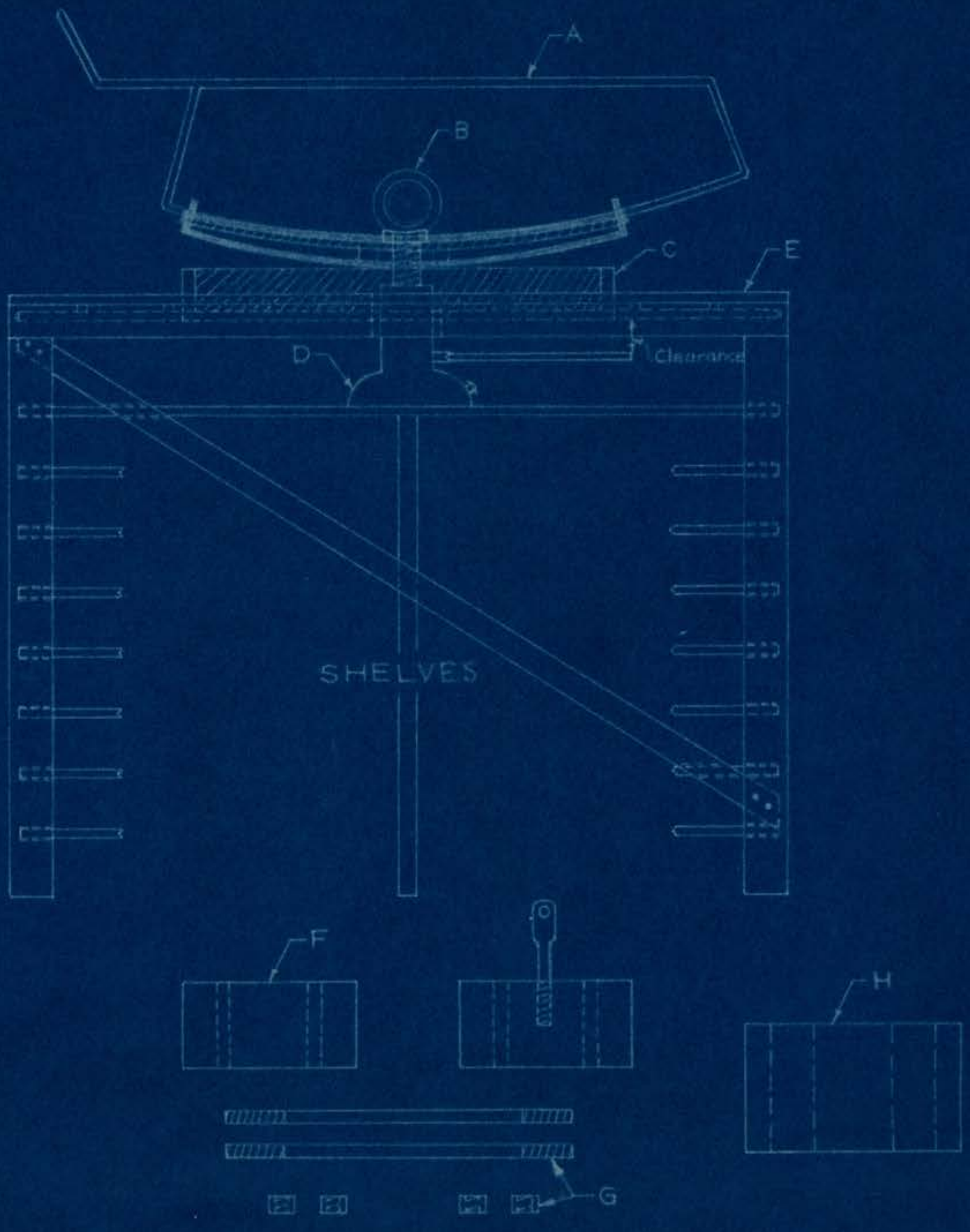
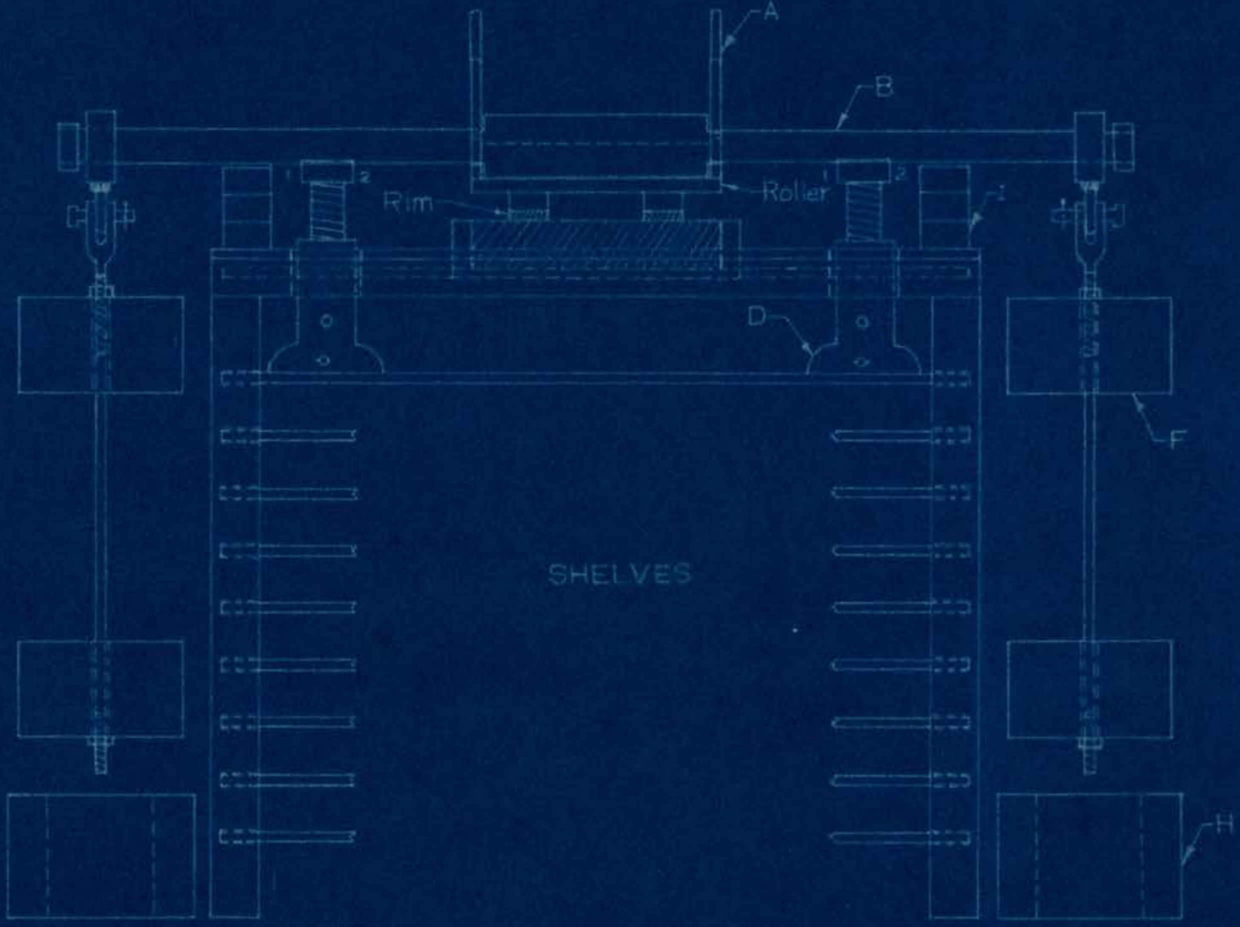


FIGURE - 2

Front View of the outfit



DESCRIPTION OF EQUIPMENT

Referring to figure 1:

Weights: 2 x 400 = 800 lbs
1 x 100 = 100 lbs (Roller, Rims)
1 x 100 = <u>100</u> lbs (Axle)
Total 1000 lbs

1000 lbs of load is half of the maximum actual load, 2000 lbs being the maximum load on 4 wheels. Since the tests were performed on two wheels only half of this 2000 lbs of load was needed.

Roller and rims were made from hard steel, weights from cast iron and boxes were made of plywood (3/4 in. thickness) and reinforced on the corners. The table was hard steel and about 3 feet in height so that the weights had enough clearance from the ground when they were attached to the axle just before the test was started.

Two jacks were used to lift the weights after each 50 cycles of loading.

Assembly has the following lettered items:

(A) Rims and their attachments.

(B) Axle which rolls freely by gravity. When it was desired to move the axle to the left (←), it was necessary to hit the heads of jacks on Side 1 with a hammer slowly as shown in figure 3. This was done by two blows for each head alternately until the desired position was reached. For the opposite direction

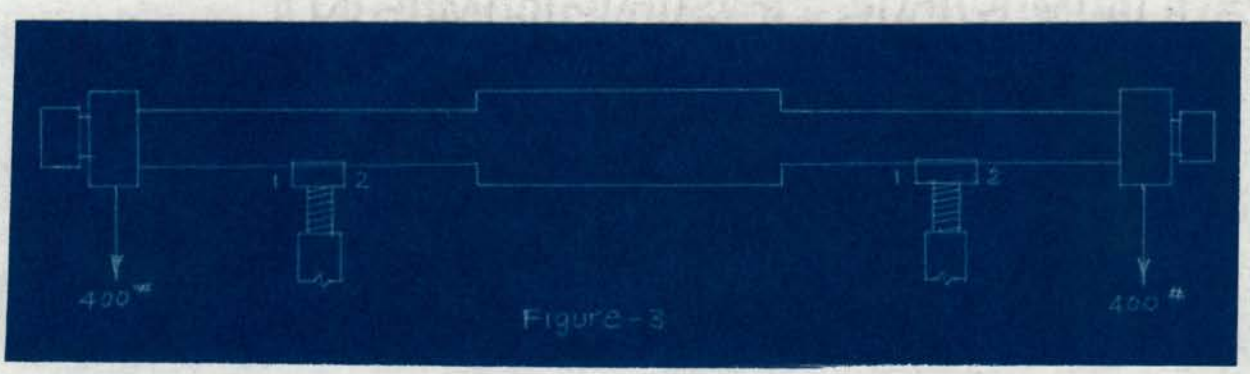


Figure-3

Side 2 must be hit with the hammer.

(C) Box with its sample pavement which can be slid under the roller after raising the axle by jacks, with one man, using two hands, holding A as high as possible.

(D) Hydraulic jacks. Clearance between the handles and the table, as shown in figure 2, seemed to be too small. In some instances it became very difficult to raise the jacks because of this small clearance. Holes should be opened on the table to increase the vertical movements of the handles in order to operate jacks properly.

(E) Table with its shelves which were made to put sample pavements on before and after using and to support jacks.

(F) Weights. Each one is 200 lbs.

(G) Weight attachments.

(H) Concrete blocks were used for safety measures.

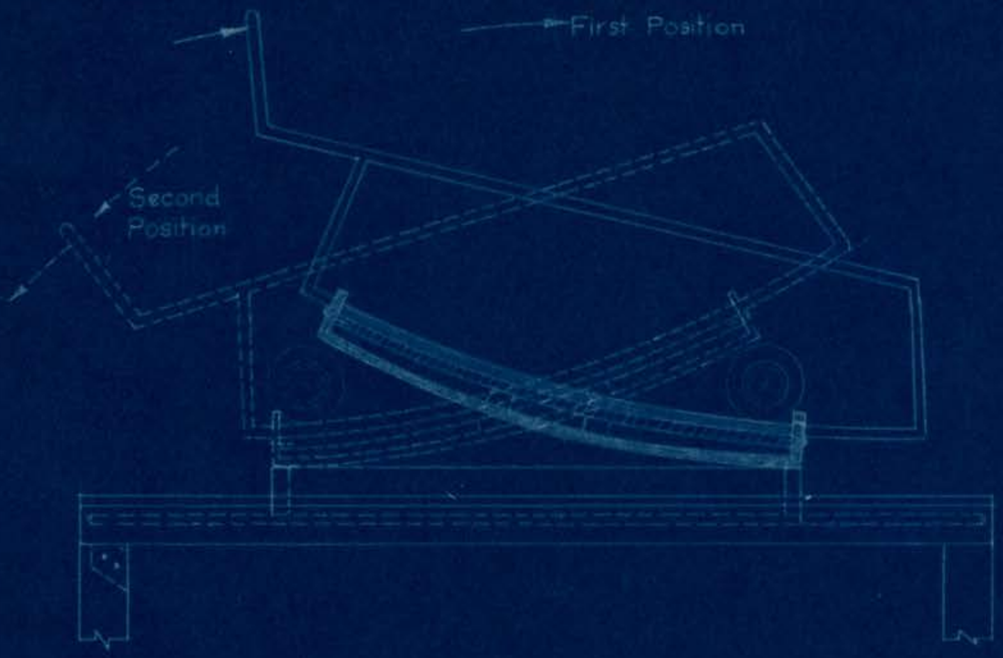
(I) Long wooden blocks were used for resting the axle and weights when the assembly was not in operation. The main purpose of this was to relieve the jacks from pressure. These blocks would also prevent the axle from falling all the way down should it become unbalanced while on the jacks. It was believed that the work could be done more safely by virtue of their use.

METHOD OF TEST

Complete outfit is shown in figures 1 and 2. Before the pavement was slid under the wheels, weights of 400 lbs. were attached on each end of the axle and by the help of two jacks the axle was raised by two persons about 4 in. for 2 in. of pavement. Then one man raised the roller while the other slid the box under it and the roller was left resting on the pavement. The weights were dropped on the roller by slowly opening the needle valves at the sides of jacks simultaneously. After this was done the next thing was a simple matter of pull-

FIGURE — 4

One Comlete Cycle



ing the handles by both hands to bring the roller to the first position as shown in figure 4. The axle rolled freely by gravity on the edges of the roller with this pull. After the first position was reached the handles were pushed or left free to bring the roller to the second position. This complete operation was counted as one cycle. Each fifty cycles the penetration of the wheel on the pavement was measured and the average of four measurements recorded. Figure 5 shows where these measurements were taken. These passes were repeated until a sufficient number of measurements were taken to construct a pass-penetration curve.

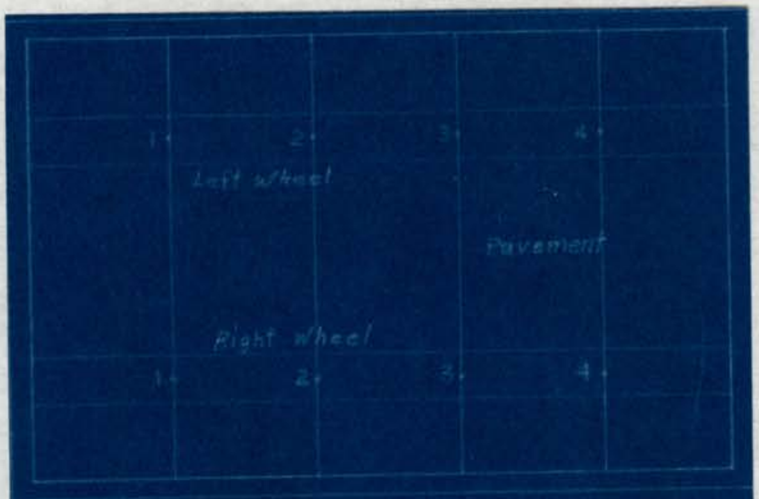


Figure-5

TEST PROCEDURES

High Type Bituminous Concrete

Introductory Remarks

By far the majority of the bituminous arterial highways in use at this time are constructed of asphaltic concrete.[1] These are the roads that are designed and constructed to carry the heaviest traffic loads.

At one time, bituminous concrete was not the most economical bituminous surfacing material for main highway use due to a lack of suitable mixing and laying equipment. Where large, crushed rock was available, penetration macadam was more economical. But the modern portable mixing plant and effectiveness and speed of the mechanical finisher have contributed substantially to a reduction in cost and the acceptance of bituminous concrete pavements over all other types for primary highways.

Bituminous concrete is a stable mix due to the close gradation control of the aggregate as well as the interlocking action of the individual particles. This interlocking action of the aggregates gives high internal friction to the pavement. It is needed for the most severe conditions, especially to resist the effect of iron wheel load which is distributed over a very small area.

Design

General steps:

1. Determination of aggregate grading and calculation of the combination of coarse aggregate, fine aggregate, and mineral filler necessary to meet the governing specifications for grading.[2] Table 2.

2. Preparation and molding of mixes containing asphalt contents on the

---

[1] Barber-Greene, Bituminous Construction, Handbook, pp. 113-114 and p. 169 1951.

[2] J. Rogers Martin, Some Fundamental Principles in Relation to Asphaltic Concrete Pavements, p. 22, Volume 16, November, 1948.

TABLE 2

COMBINED GRADING OF AGGREGATES

Lab. No.	A		B		C		Comb. Grdg.	Mid Point	Spec. Limits
Size	Tot. %	55	Tot. %	30	Tot. %	15			
Pass. Ret.									
2"									
1-1/2"									
1"									
3/4"	100	55	100	30	100	15	100	100	100
1/2"	100	55	100	30	100	15	100	97.5	95-100
3/8"									
4	38	21	100	30	100	15	66	67.5	55- 80
10	6	3.3	98	30	100	15	48.3	47.5	40- 55
40	3	1.6	54	16	96	14.8	32.8	28.5	20- 37
80	2	1.1	27	8.0	56	8.5	17.5	17.5	10- 25
200	1	.55	3	0.9	32	4.8	5.25	6	4- 8

Ali Kirkağaçlıoğlu

TABLE 3

CHANDLER CRUSHED STONE

Weight of Sample 1515 g.

Size	Grams Retained	% Retained	% Passing
1-1/2"	0	0	100
1"	0	0	100
3/4"	0	0	100
1/2"	267	17.6	82.4
3/8"	533	35.2	71.6
4	1127	74.4	25.6
10	1325	87.2	12.5
40	1426	94.0	6.0
80	1464	96.7	3.3
200	1491	98.4	1.6
P 200	24	1.6	

TABLE 4

COARSE SAND

TABLE 5

FINE SAND

Grams Retained	% Retained	% Passing	Size	Grams Retained	% Retained	% Pass.
4	0.8	99.2	4	0	0	100
45	9.0	91.0	10	1	0.2	99.8
303	60.4	29.6	40	3.5	0.7	99.3
497	99.0	1.0	80	104.0	20.8	79.2
501	99.8	0.2	200	375.0	75.0	25.0
1	0.2	0.2	P200	125.0		

Weight of Sample 502 g.

Weight of Sample 500 g.

DATA ON MOLDED SPECIMENS

TABLE 6

$$\text{Sp. gr.} = d = \frac{a}{b - c - \frac{b - a}{G_p}}$$

$$D = \frac{100}{\frac{100 - W_a}{G_c} + \frac{W_e}{G_a}}$$

$G_p = 0.9$

$G_a = 1.00$

a = wt. spec. in air
b = wt. spec. par. in air
c = wt. spec. par. in water
D = Theo. sp. gr. of spec.
R = % Density = $\frac{d}{D} \times 100$

Asph. Cont. %	Spec. No.	a	b	c	b-c	b-a	$\frac{b-a}{G_p}$	d	D	% Density	
										Ind.	Ave.
5.0	1	983.7	1019.6	532.3	487.3	35.9	39.32	2.19	2.37	92.5	92.5
5.5	1	922.0	960.0	516.1	443.9	38.0	42.2	2.29	2.36	97.0	96.0
	2	945.0	984.1	519.0	465.1	39.2	43.5	2.24	2.36	95.0	
6.0	1	951.5	972.7	531.2	441.5	23.2	25.8	2.28	2.34	97.4	97.2
	2	949.5	980.1	530.0	450.1	28.6	30.7	2.27	2.34	97.0	
6.5	1	952.0	989.8	533.4	456.4	37.8	40.5	2.29	2.325	98.5	98.5
	2	947.0	978.0	530.3	447.7	31.0	33.2	2.29	2.325	98.5	
7.0	1	946.6	992.9	533.1	459.8	46.3	49.7	2.31	2.31	100.0	99.7
	2	959.6	1012.9	536.7	476.2	53.3	59.2	2.31	2.31	99.5	

Hveem Stability

Asphalt Content - %	5.0		5.5		6.0		6.5		7.0	
Spec. No.	1	2	1	2	1	2	1	2	1	2
Spec. Ht.-in.	2.125		1.97	2.06	1.97	2.031	2.031	2.0	1.97	2.0
Gage Rage at 5000#	69.5		54	49.5	70.0	60.0	70.0	68.0	125	95
Final Disp.-in.	.19		.178	.179	.16	.145	.171	.154	.181	.178
Hveem Stability	35.6		45	47.0	39.7	46.6	38	41	21.3	28.8
Ave. Hveem Stability	35.6		46		43.15		39.5		25.5	
Relative Stability	31.0		41.0		47.5		34.5		20.0	

low side of the specification, the high side, the middle, and the quarter points. For instance, since the specifications define an asphalt content of from 5 to 7 per cent, specimens were made with 5.0, 5.5, 6.0, 6.5, and 7.0 per cent by weight. Table 6.

3. Determination of the specific gravity of the molded specimen. Table 6.

4. Determination of stability by the Hveem Stabilometer. Table 6.

5. Determination of the optimum asphalt content by use of the data from 2, 3, and 4. Figure 6.

The design was made meeting the specifications in the Oklahoma Highway Department stencil 411-5, 7-11-47 for the Type B mix. The asphalt content is from 5.0 to 7.0 per cent, with grading as shown in Table 2.

Materials

Chandler crushed stone - aggregate retained on the No. 10 sieve. It was clean and free from an excess of dust and it was of reasonably uniform quality. The screen analysis is shown in Table 3.

Coarse sand - material passing a No. 10 and retained on a No. 200 sieve. It was clean, tough, rough surfaced grains, free from clay, loam and other foreign matters. Screen analysis shown in Table 4.

Fine sand - stone dust passed the No. 200 sieve. It consisted of thoroughly dry limestone dust. It was free from lumps and loosely bonded aggregations. The screen analysis shown in Table 5.

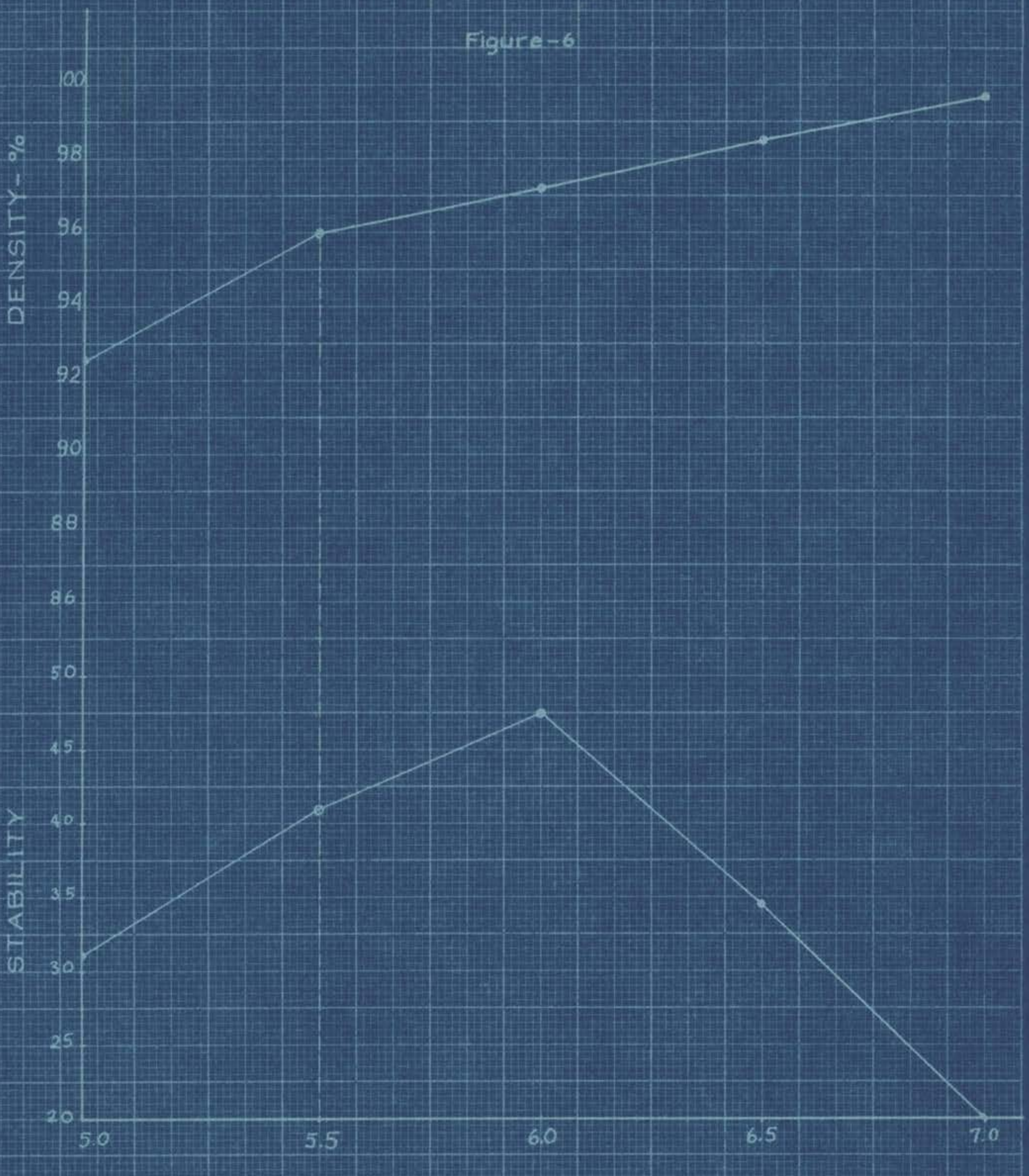
Asphalt - asphalt cement used, manufactured by Anderson Pritchard Corporation. It has 90 penetration.

These materials conformed to standard Oklahoma Highway Department specifications.

Sample Calculation

Specific gravity of mix (G) = 2.26 Table 6
Density = 2.26 x 62.4 = 141 lbs per cu ft
141 x 27/36 = 106 lbs per sq yd in.
Volume of Box = 12 x 18 x 2 = 432 cu in.
432/1728 = 0.28 cu ft
0.28 x 141 = 35.3 lbs
35.3 x 454 = 16,000 grams required to fill box exactly at 96% density

Figure-6



OPTIMUM ASPHALT CONTENT - 5.5 %

TEST RESULTS

		Left Wheel	Right Wheel
Cycles	Line No.	Average Vert. Deformation in.	Average Vert. Deformation in.
50	1	0.03125	0.02343
	2	0.02345	0.02343
	3	0.03125	0.03125
	4	0.03125	0.01562
		0.1172	0.0937
		= 0.1172/4 = 0.0293	= 0.0937/4 = 0.0234
102	1	0.0390	0.02734
	2	0.0469	0.02734
	3	0.0390	0.03125
	4	0.0390	0.03906
		0.1640	0.1250
		= 0.1640/4 = 0.0410	= 0.1250/4 = 0.03124
153	1	0.0624	0.0581
	2	0.0624	0.0703
	3	0.0547	0.0390
	4	0.0486	0.0486
		0.2268	0.2143
		= 0.2268/4 = 0.0567	= 0.2143/4 = 0.0536
204	1	0.0780	0.0831
	2	0.0780	0.0859
	3	0.0547	0.0468
	4	0.0625	0.0547
		0.2733	0.2706
		= 0.2733/4 = 0.0683	= 0.2706/4 = 0.0676
254	1	0.1092	0.0781
	2	0.1092	0.0781
	3	0.0781	0.0312
	4	0.0781	0.0625
		0.3746	0.250
		= 0.3746/4 = 0.0936	= 0.25/4 = 0.0625
305	1	0.1092	0.0625
	2	0.1092	0.0781
	3	0.0781	0.0625
	4	0.0781	0.0625
		0.3746	0.2656
		= 0.3746/4 = 0.0936	= 0.2656/4 = 0.0664

TEST RESULTS (CONT'D)

		Left Wheel	Right Wheel
Cycles	Line No.	Average Vert. Deformation in.	Average Vert. Deformation in.
356	1	0.1092	0.0781
	2	0.1092	0.1093
	3	0.0781	0.0625
	4	0.0781	0.0781
		0.3746	0.3280
		= 0.3746/4 = 0.0936	= 0.328/4 = 0.082
406	1	0.1092	0.0781
	2	0.1092	0.1093
	3	0.0781	0.0625
	4	0.0781	0.0781
		0.3746	0.328
		= 0.3746/4 = 0.0936	= 0.328/4 = 0.082
457	1	Same as above	Same as above
	2		
	3		
	4		
507	1	Same as above	Same as above
	2		
	3		
	4		

6.0% Asphalt
16,000 x 0.06 = 960 g

Aggregate #1 (16000 - 960) x .55 = 8270 g.
+ 4 8270 x 0.38 = 3142.5 g
- 4 8270 x 0.62 = 5127.5 g
Aggregate #2 (16000 - 960) x 0.30 = 4250 g
Aggregate #3 (16000 - 960) x 0.15 = 2250 g

Discussion of Results

Observation of figure 7 reveals that after 300 passes the curves level off. This means that the deformation of the pavement was due to compaction only. It is self-evident that if an appreciable portion of the deformation had been due to plastic flow or shear, the curves would not have leveled off in this manner.

Penetration of 3/4 inch is commonly used as a criterion for complete failure of a flexible pavement. In this respect it is highly significant that the maximum penetration obtained in the pavement under test was less than 0.1 inch.

It is also a safe conclusion that this experiment was made in the worst condition in that the wheels were confined over a two inch width of the pavement for 500 times. In practice this cannot exist. It appears to be a safe assumption that the wheel passes would actually be distributed over a path with a width of at least 20 inches. This reduces the maximum penetration (0.094) to

$$0.094\ (2/20) = 0.0094$$

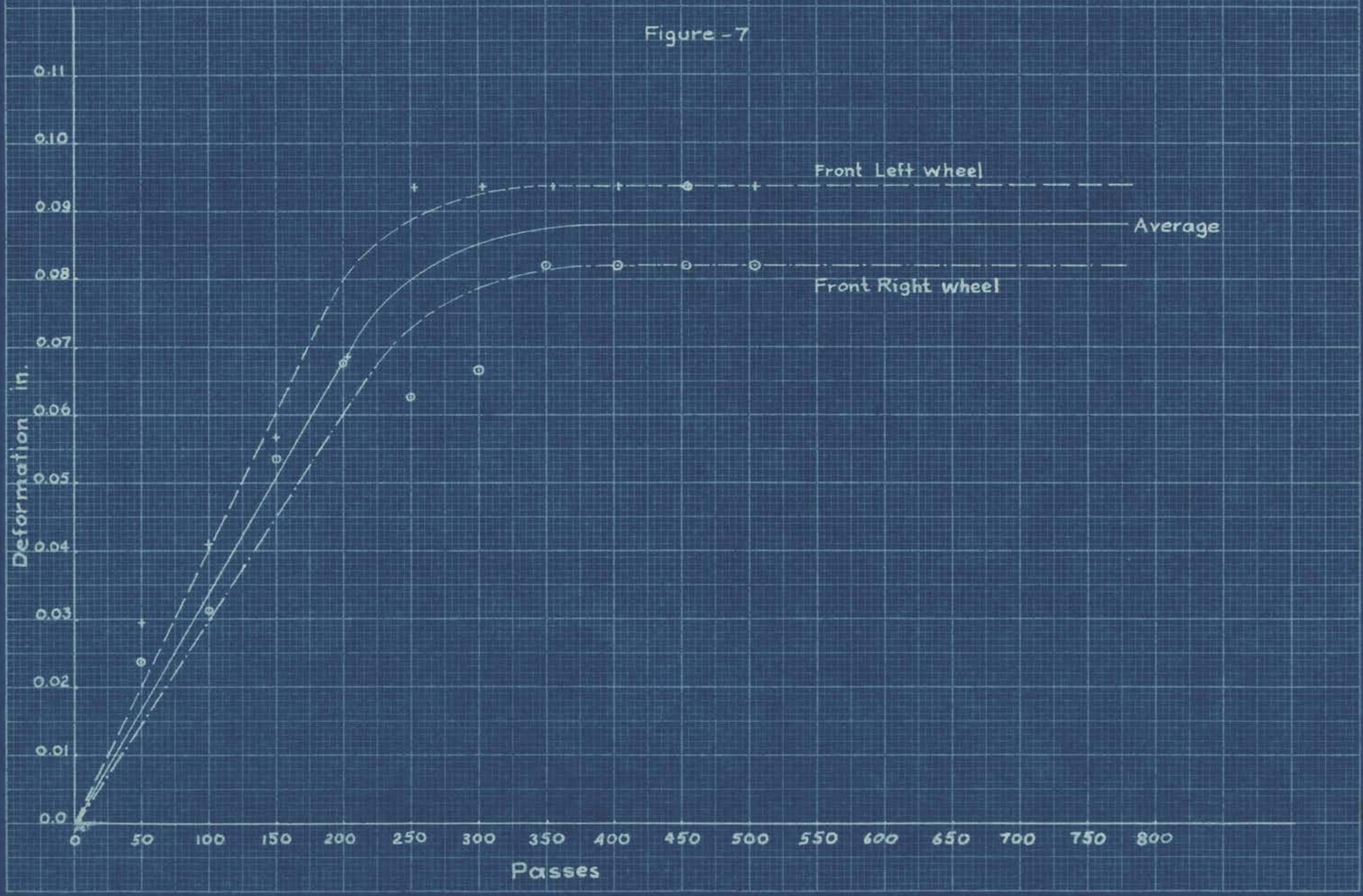
for 300 passes.

Examination and test results indicated that all of the deformation was due to compaction and some crushing of stone and not plastic flow.

Recommendations

1. The gradation of the aggregate is important as it determines, for the

Figure - 7


Front Left wheel
Average
Front Right wheel
Deformation in.
0.0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0
50
100
150
200
250
300
350
400
450
500
550
600
650
700
750
800
Passes

most part, the mechanical stability of the bituminous mix.

2. 96-98 density is necessary.

3. Sub-base with CBR (California Bearing Ratio) at least 60 with good compaction.

4. If possible, tough crushed stone will give better results.

5. It is better practice to blend three separate aggregates made up of two types of sand and one of crushed stone as in the sample mix under consideration.

6. The results of this test show that sufficient shearing resistance will be present if the Hveem Stability is at least 45%.

7. This is a satisfactory pavement for withstanding the punishing effect of iron wheel loads.

Sheet Asphalt

Introductory Remarks

Although sheet asphalt surfaces are not ordinarily used on highways because of their higher cost, it is general practice to use them in the cities. Since iron wheeled carts cannot be prevented from entering the cities, this kind of pavement was also tested under the roller. Another reason for this testing was purely mechanical. It was felt that some of the deformation obtained with the high type asphaltic concrete may have caused crushing in the large aggregate. Therefore by using sheet asphalt (top size 10 mesh) it was thought this might be eliminated.

The grading was formulated by the writer and Professor J. Rogers Martin as shown in the tables.

Design

General Steps

The method of procedure was the same as that given for the high type asphaltic concrete pavement previously described.

Materials

Coarse sand - passing No. 10 and retained No. 40 laboratory sieves. It consists of stone screening, composed of clean, tough, rough surfaced grains, free from clay, loam and other foreign matter. Table 7.

Fine sand - same material used for asphaltic concrete pavement. Table 8.

Mineral filler - passing No. 200 laboratory sieve. It consists of thoroughly dry limestone dust. It is free from lumps and loosely bonded aggregations. Table 9.

Asphalt - same asphalt cement used for asphaltic concrete pavement.

These materials conform to standard Oklahoma Highway Department specifications.

TABLE 7

SCREEN ANALYSIS

Weight of Sample 1000 g.

Size	Grams Retained	% Retained	% Passing
4	0.0	0.0	100
10	0.0	0.0	100
40	676.5	67.65	32.5
80	984.0	98.40	1.6
200	997.5	99.75	0.25
P 200	2.5		

TABLE 8

SCREEN ANALYSIS

Grams Retained	% Retained	% Passing
0	0	100
0	0	100
247	24.7	75.3
824	82.4	17.6
958	95.8	4.2
42		

Weight of Sample 1000 g.

TABLE 9

Size	Grams Retained	% Retained	% Passing
4	0	0	100
10	0	0	100
40	0	0.0	100
80	291	29.1	70.9
200	835	83.5	16.5
P200	165		

Weight of Sample 1000 g.

TABLE 10

$$\text{Sp. gr.} = d = \frac{a}{b - c - \frac{b - a}{G_p}}$$

$G_p = 0.9$ $G_a = 1.00$

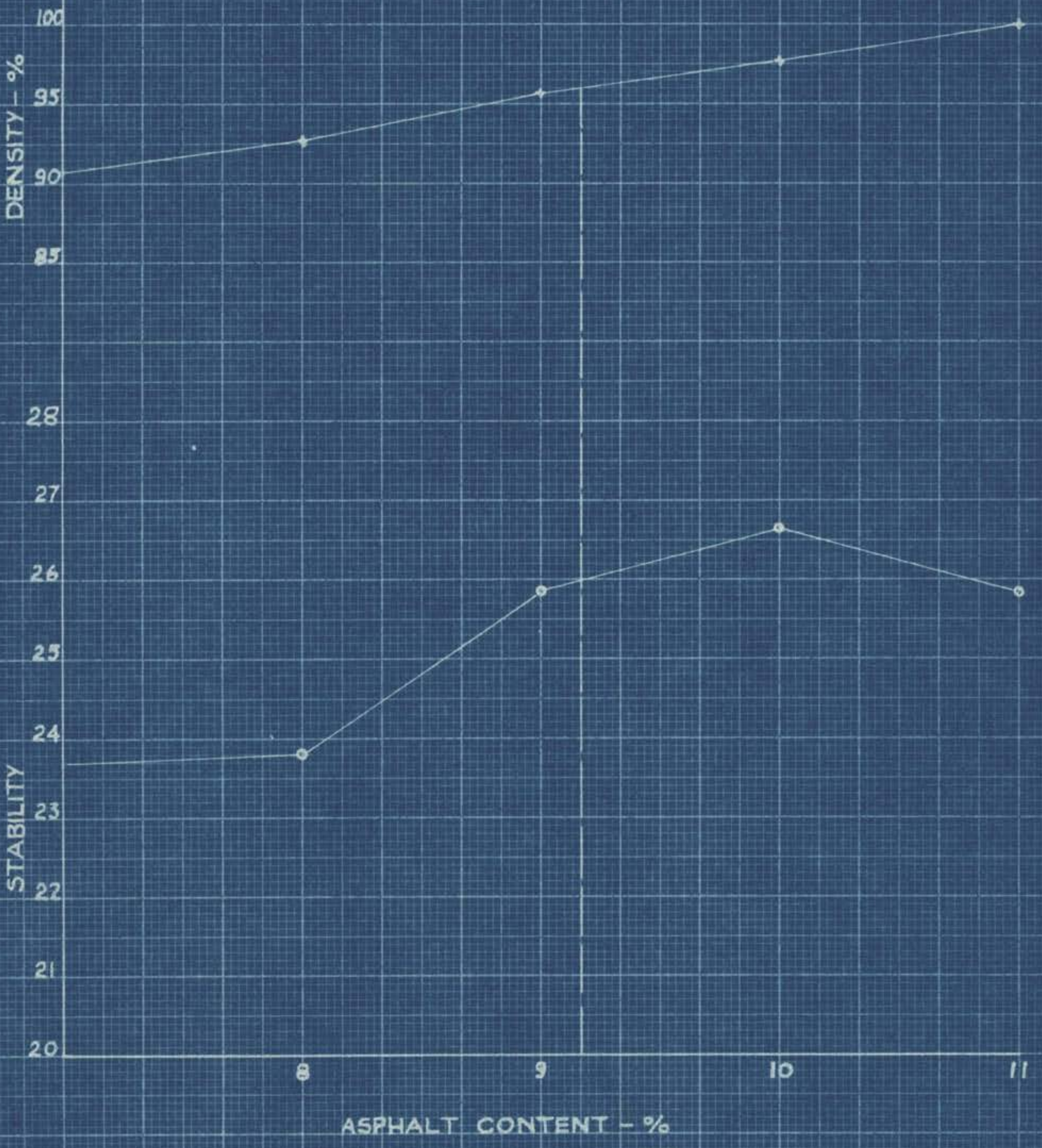
a = wt, spec. in air
b = wt. spec. par. in air
c = wt. spec. par. in water
D = Theo. sp. gr. of spec.
R = (d/D) x 100 = % Density

Asph. Cont. %	Spec. No.	a	b	c	b-c	b-a	$\frac{b-a}{G_p}$	d	D	% Density	
										Ind.	Ave.
7	1	878.5	904.5	444.0	460.5	26.0	28.9	2.02	2.23	90.7	91.05
	2	880.5	906.0	444.5	461.5	25.5	28.34	2.04	2.23	91.4	
8	1	882.5	907.5	449.0	458.5	25.0	27.8	2.05	2.20	93.2	92.8
	2	882.5	906.0	445.5	460.5	23.5	26.1	2.03	2.20	92.4	
9	1	894.5	922.0	465.0	457.0	27.5	30.6	2.10	2.18	96.4	95.7
	2	887.0	918.5	454.0	464.5	31.5	35.0	2.07	2.18	95.0	
10	1	901.0	939.0	465.0	474.0	38.0	42.2	2.09	2.145	97.5	97.9
	2	904.0	929.5	472.0	457.5	25.5	28.34	2.11	2.145	98.3	
11	1	909.0	937.0	477.0	460.0	28.0	31.1	2.12	2.12	100.0	100.0
	2	909.0	938.5	477.0	461.5	29.5	32.6	2.12	2.12	100.0	

Hveem Stability

Asphalt Content - %	7		8		9		10		11	
Spec. No.	1	2	1	2	1	2	1	2	1	2
Spec. Ht.-in.	2.03	2.06	2.06	2.06	2.03	2.06	2.06	2.06	2.06	2.03
Gage Rage at 5000#	123	124	121	124	110	122	110	116	110	122
Final Disp.-in.	.159	.163	.159	.169	.157	.158	.166	.149	.156	.153
Hveem Stability	24	23.4	24.4	23.2	27.5	24.2	26.2	27.0	27.5	24.2
Ave. Hveem Stability										
Ave. Hveem Stability	23.7		23.8		25.85		26.6		25.85	

Figure—8



OPTIMUM ASPHALT CONTENT – 9.1 %

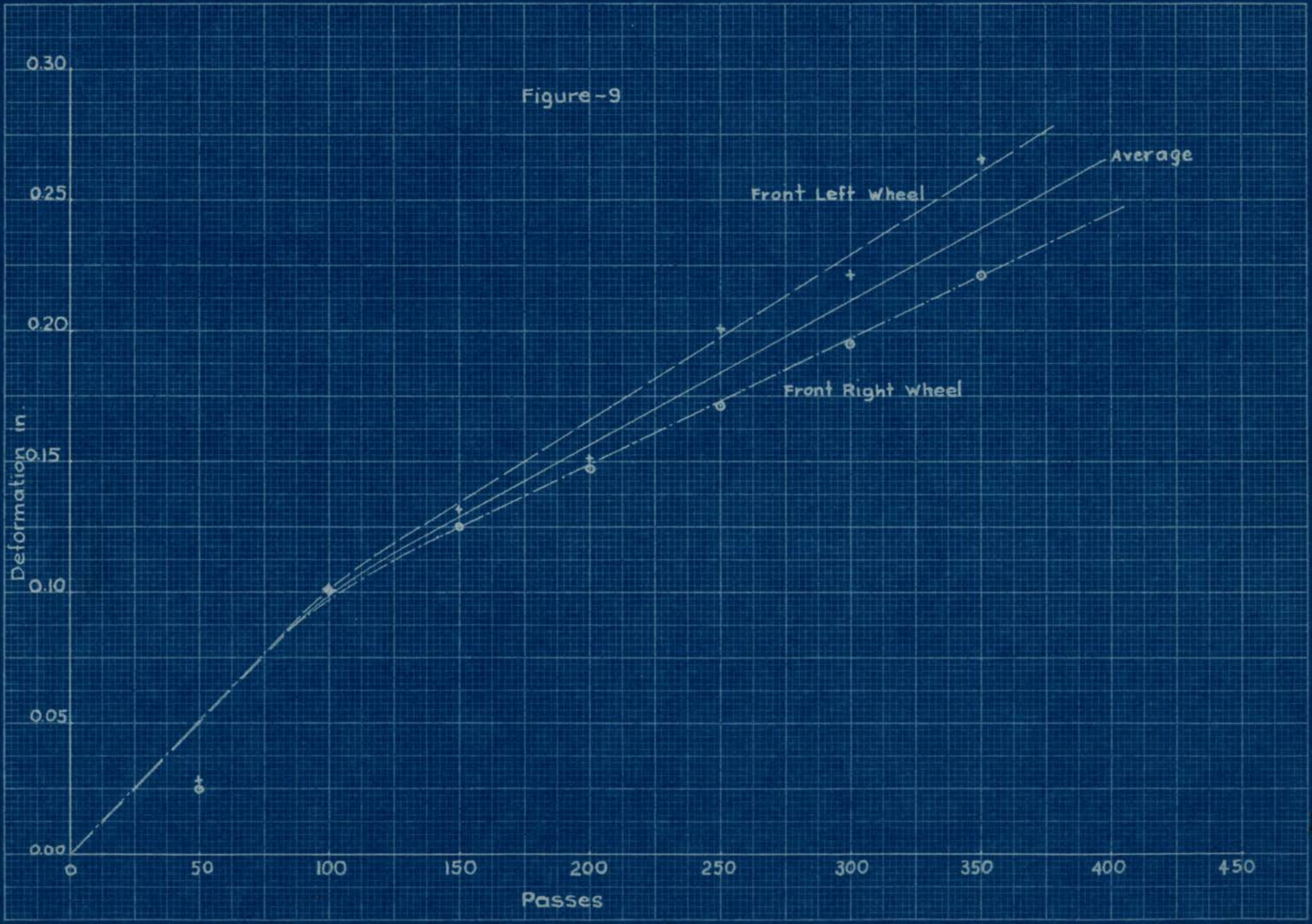


Figure-9

0.30
0.25
0.20
0.15
0.10
0.05
0.00
Deformation in.
0
50
100
150
200
250
300
350
400
450
Passes
Front Left Wheel
Average
Front Right Wheel

Specification

1 Passing	Spec. Limits	Mid-Point
#10	90 - 100	95
#40	50 - 70	60
#80	30-- 42	36
#200	8 - 14	12

or

2 Passing	Retained	Per Cent
#10	#40	40
#40	#80	24
#80	#200	24
#200	P200	12

No. 2 was used. In this specification percentages were calculated by taking the differences of mid-points of No. 1 specification of each mesh.

Sample Calculation

Specific gravity of mix (G) = 2.085 Table 10
= 2.085 x 62.4 = 130 lbs per cu ft
= 130 x 27/36 = 97.6 lbs per sq yd in.
Volume of box = 12 x 18 x 2 = 432 cu in.
432/1728 = 0.25 cu ft
0.25 x 130 = 32.5 lbs
32.5 x 454 = 14750 grams required to fill box exactly at 96% density

9.1% Asphalt
15000 x 0.091 = 1364 g

Weight of aggregates

#10 - #40
(15000 - 1364) x 0.4 = 5455 g

#40 - #80
(15000 - 1364) x 0.24 = 3272 g

#80 - #200
(15000 - 1364) x 0.24 = 3272 g

#200 passing
(15000 - 1364) x 0.12 = 1637 g

TEST RESULTS

Cycle	Line No.	Left Wheel	Right Wheel
50	1	0.0781	0.0781
	2	0.0938	0.0781
	3	0.0938	0.0938
		0.2657	0.2500
		= 0.2657/4 = 0.0663	= 0.25/4 = 0.0625
101	1	0.125	0.125
	2	0.140	0.125
	3	0.156	0.156
		0.421	0.406
		= 0.421/4 = 0.105	= 0.406/4 = 0.1015
152	1	0.1560	0.1560
	2	0.1875	0.1560
	3	0.1875	0.1875
		0.5310	0.4995
		= 0.531/4 = 0.133	= 0.4995/4 = 0.125
203	1	0.1875	0.1875
	2	0.2190	0.1875
	3	0.2030	0.2190
		0.6095	0.5940
		= 0.6095/4 = 0.1520	= 0.594/4 = 0.1485
253	1	0.250	0.219
	2	0.280	0.219
	3	0.280	0.250
		0.810	0.688
		= 0.81/4 = 0.202	= 0.688/4 = 0.172
304	1	0.280	0.25
	2	0.312	0.25
	3	0.312	0.28
		0.904	0.78
		= 0.904/4 = 0.223	= 0.78/4 = 0.195
355	1	0.312	0.2800
	2	0.375	0.2985
	3	0.375	0.3120
		1.062	0.8905
		= 1.062/4 = 0.266	= 0.8905/4 = 0.223

Definite evidence showed that plastic flow was taking place.

Discussion of Result

It is understood that the deformation which occurred in this test was plastic deformation. This is the major cause of deformation of the flexible pavement. It occurs when the pore pressure and other horizontal forces produced by the load are enough to displace the material. As the pore pressure greatly reduces the frictional resistance of the material and also, at the same time, greatly increases the shearing stresses by acting equally in all directions, it is the principle cause of lateral displacement and failure of pavements under dynamic load repetitions. In this case, the pavement does not return to its original position after the load is removed. Although, under rapid moving wheel loads, the time of loading may not be enough to cause excessive deformations in a few repetitions, the movement is progressive, and rutting, cracking and complete failure result after a sufficiently large number of load repetitions.

Plastic deformation is even more serious as the magnitude of the deflection rapidly increases with the wheel load intensity. Disintegration of the pavement soon occurs if its thickness and strength are not sufficient to reduce to an extremely small amount the plastic deformation resulting from a single application of a moving wheel load. In addition to causing rutting, plastic deformation also causes flexible pavements and bases to weave and crack; thus progressively reducing their strength which in turn increases the magnitude of the deflection. This completes a vicious circle which rapidly destroys the pavement.

Recommendations

1. Either a small excess or deficiency of any aggregate size, or of the bitumen content, reduces the pavement stability. Therefore great care must be given to gradation.

2. For colder climates and for little traffic softer asphalt cement must

be used.

3. It must be used only for top surface course.

4. The durability of the pavement is dependent upon the laying temperature so that it must be controlled.

5. The use of sheet asphalt is rapidly declining in favor of asphaltic concrete, because the latter is much more resistant to heavy traffic and is, in general, less expensive. It should be used only when it is impossible or impractical to employ asphaltic concrete.

High Type Concrete Pavement

Introductory Remarks

Since concrete pavement is also used in Turkey, it was felt that we should make tests to ascertain, if possible, a means of reducing the detrimental effect of iron wheel loads at the pavement joints as this is the point at which the major portion of the trouble occurs. Wearing starts at the joints and progresses outward.

Four different joints were constructed in the hope that one or more would withstand the iron wheel action.

1. In this joint a 2" x 2" hard wooden block (oak) was used as shown in figure 10.

2. This is an ordinary 3/4 in. expansion joint as commonly used on concrete highways at the present time.

3. Iron angle is used with dimensions and placements as shown in figure 10.

4. Neat cement was used in the other side as indicated in figure 10.

Design

Requirements

Material	Specific Gravity (SSD)	Unit Weight (lb per cu ft loose density)
Rock	2.58	95
Sand	2.61	105
Cement	3.12	94

Cement factor - 6.0

Water cement ratio - 6.0 gals per sack

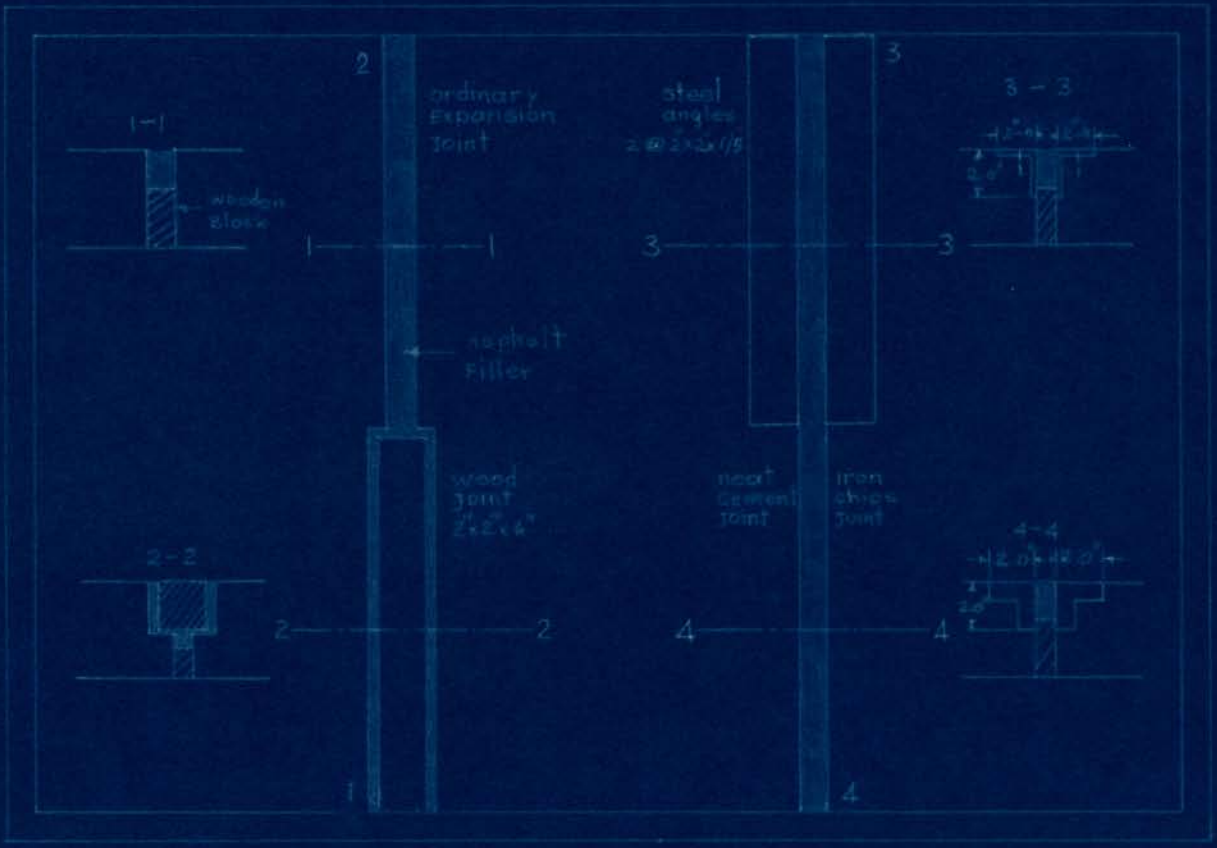
b/b_o - .75

Mix

1. Solid volumes of materials

Density of cement = 3.12 x 62.4 = 194 lbs per cu ft

Figure -10


2
ordinary
Expansion
Joint
steel
angles
2 @ 2×2×1/5
3
1-1
wooden
Block
1 — 1
3 — 3
3 - 3
2.0"
2.0"
2.0"
asphalt
Filler
wood
joint
2"×2"×4"
neat
Cement
Joint
iron
chips
Joint
2-2
2 — 2
4 — 4
4-4
2.0"
2.0"
2.0"
1
4

Density of sand = 2.61 x 62.4 = 163 lbs per cu ft

Density of rock = 2.58 x 62.4 = 162 lbs per cu ft

Since the cement factor is 6.0, for 1 cu yd batch sacks of cement required.are 6.

6 x 94 = 576 lbs cement

Solid volume of cement = 576/194 = 2.97 cu ft

b/b_o = cu ft loose rock/cu ft of concrete = 0.75

cu ft loose rock = 0.75 x 95 x 27 = 1922 lbs per cu yd

Solid volume of rock = 1922/162 = 11.88 cu ft

6 x 6 = 36 gals of water in the batch

Solid volume of water = 36/7.5 = 4.8 cu ft

2.97 + 11.88 + 4.8 = 19.65 cu ft

Solid volume of sand = 27 - 19,65 = 7.35 cu ft

2. Weights of materials in 1 cu yd

Cement - 194 x 2.97 = 576 lbs

Rock - 162 x 11.88 = 1922 lbs

Sand - 163 x 7.35 = 1200 lbs

Water - by volume

3. Weights to give size of batch designed

Volume of box = 12 x 18 x 4 = 864 cu in.

864/1728 = .5 cu ft

.5/27 = 0.0185

Cement - 576 x 0.0185 = 10.656 lbs

Rock - 1922 x 0.0185 = 35.557 lbs

Sand - 1200 x 0.0185 = 22.2 lbs

Water - 36 x 0.0185 = 0.666 gal

1 gallon = 3785 cu cm

- 0.666 x 3785 = 2520 cc

Test Results

In this experiment it was impractical to attempt to obtain numerical data. Hence the results of the tests were judged by visual observation.

Discussion of Results

Joint #1 was unsatisfactory as expected. Failure began at 500 cycles and continued for the rest of the test. However, it was observed that a portion of the area which became accidentally coated with asphalt from the joint did not show spalling. This lends strong evidence to the fact that the asphalt exerts a protective action by a padding effect, and shows excellent promise as a possible means of reducing or eliminating spalling at the joints.

Joint #2 showed considerable improvement over Joint #1 in that spalling occurred only on one side of the joint and at one edge of the rim. Spalled area was much smaller than that in Joint #1.

Joint #3 showed improvement over Joint #2. Like Joint #2 failure occurred on only one side of the joint and one side of the rim. Spalled area was considerably smaller than that in Joint #2.

Joint #4 performed in an excellent manner. As with Joint #1 both sides of the joint became coated with asphalt from the joint seal. It is, therefore, difficult to say whether the excellent results were obtained by virtue of asphalt coating or the neat cement (water, cement ratio is equal to 5.0).

Recommendations

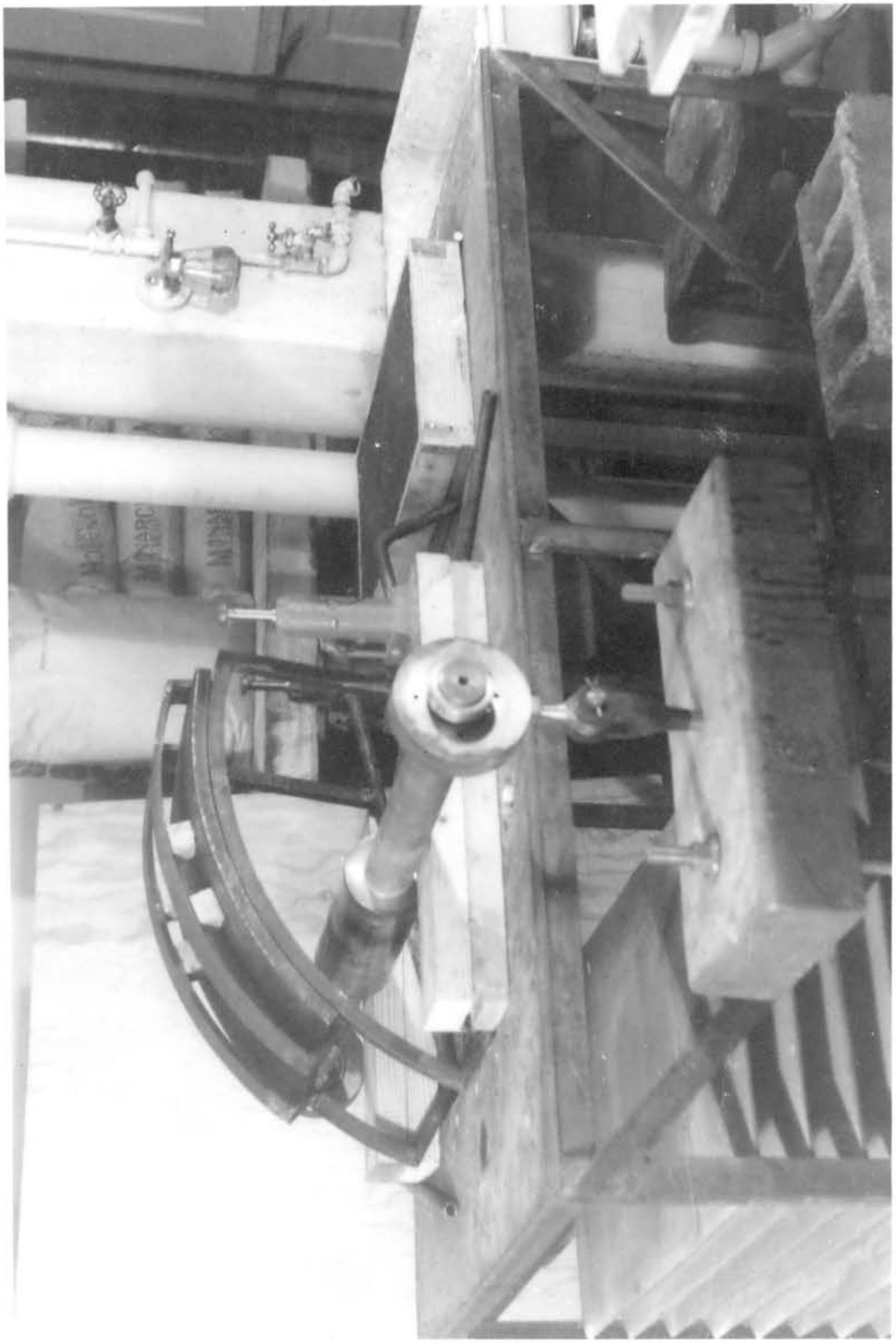
1. By giving careful attention to proportioning neat cement concrete is advisable for experimental purposes until further definite results are obtained.

2. Coating the joints thinly for 2 inches on either side with asphalt

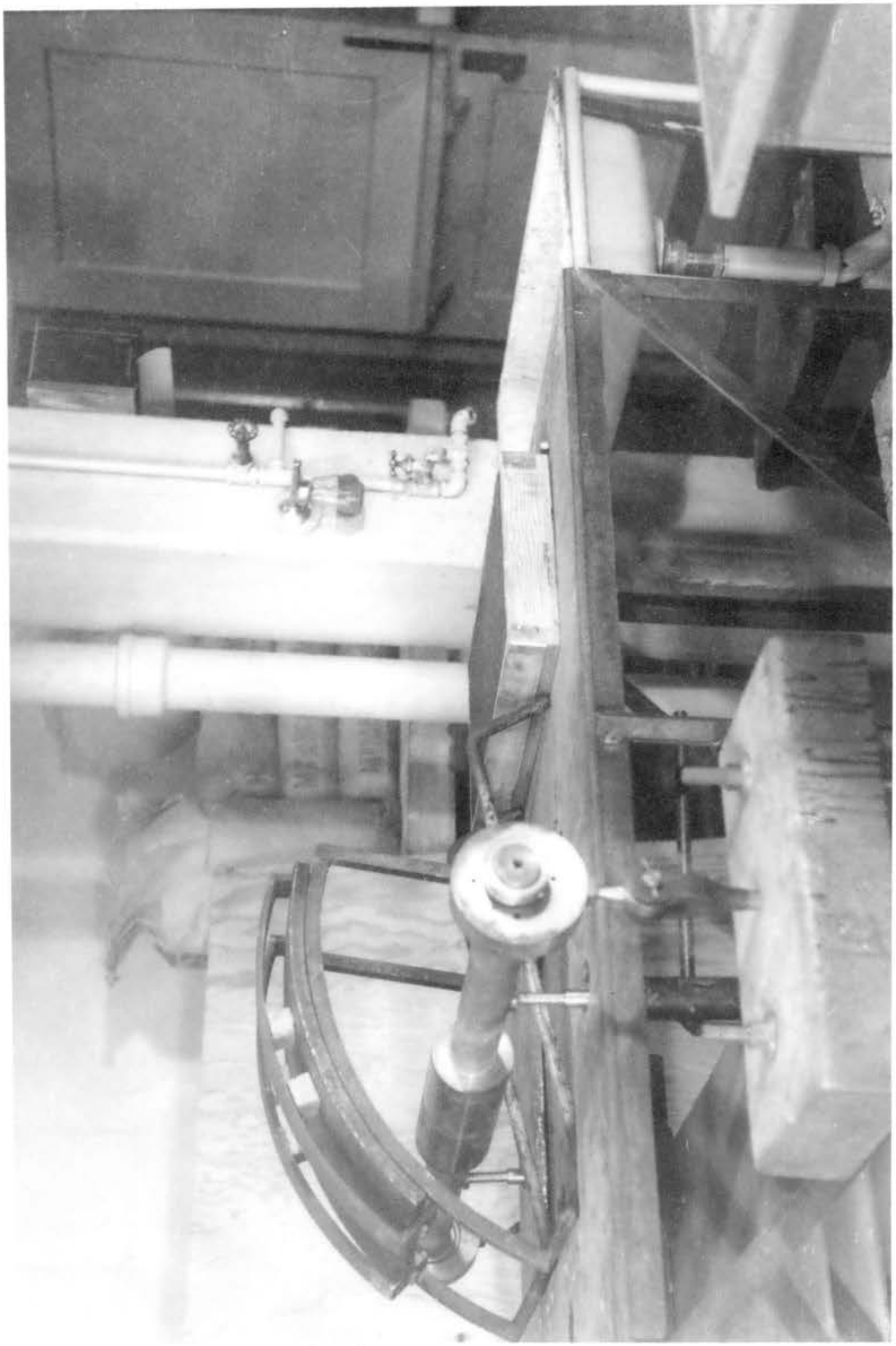
might take the shock of two hard surfaces as the test results showed. Therefore, it could be used for experimental purposes until further definite results are obtained.

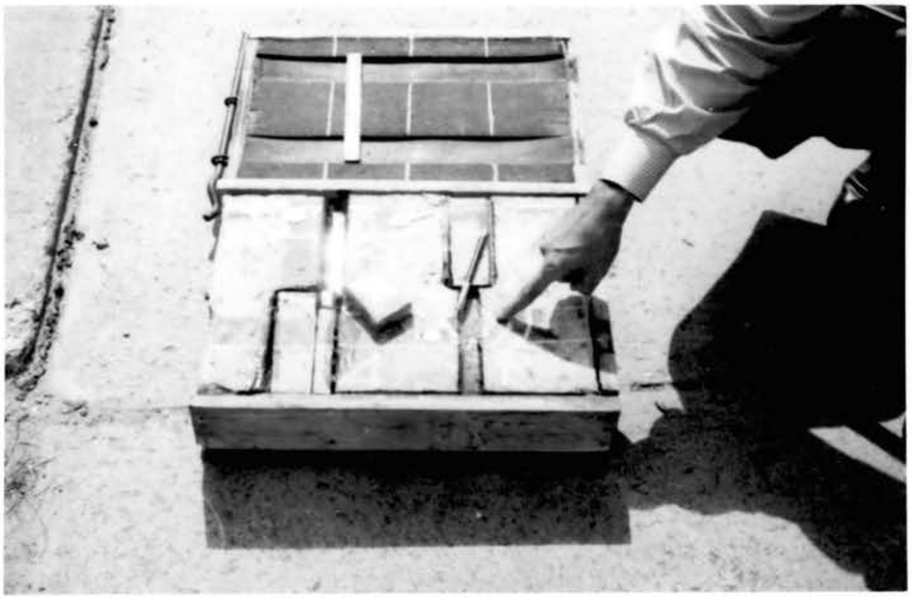

EXPANDED PERLITE

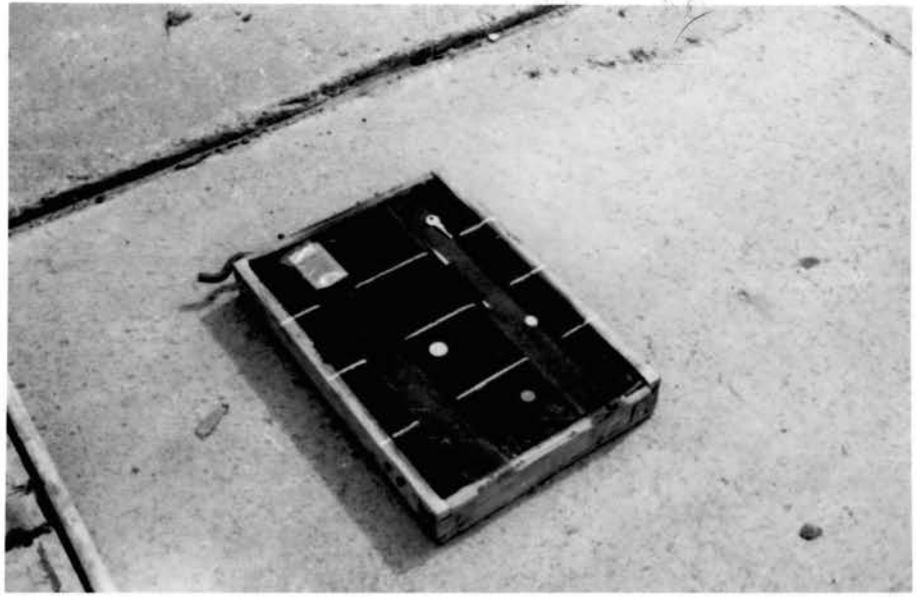
EXPANDE

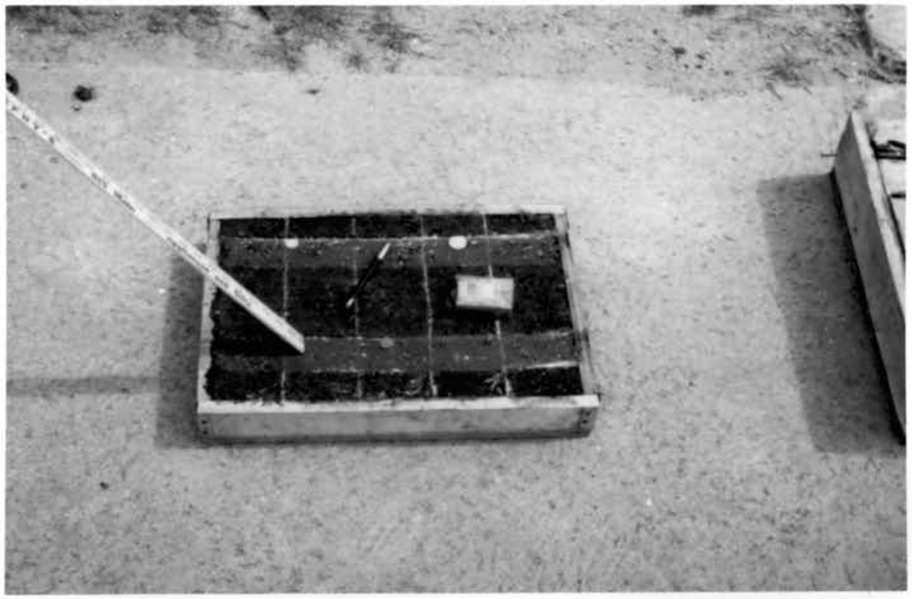


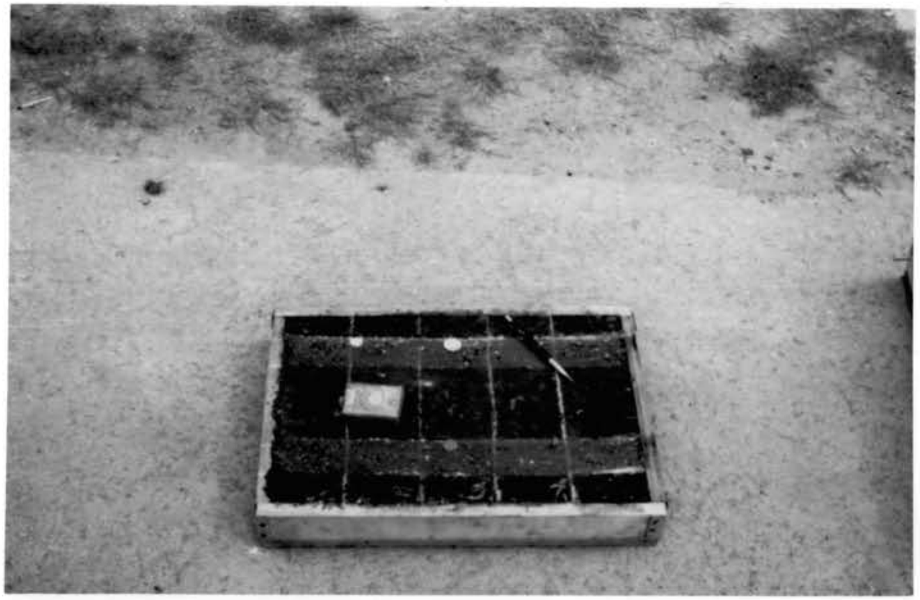

EXPANDED PERLITE

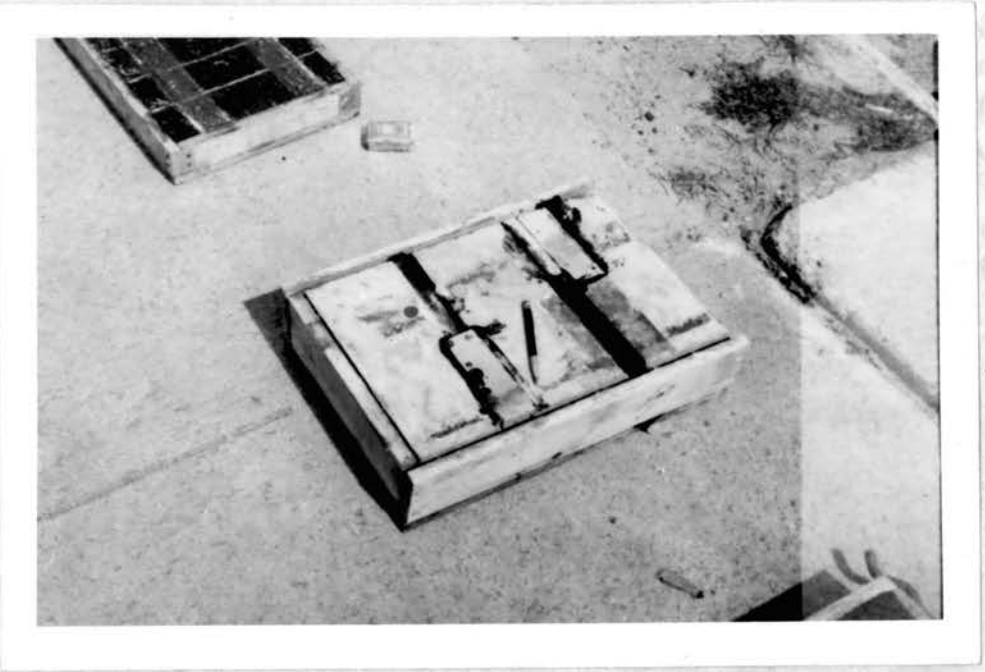


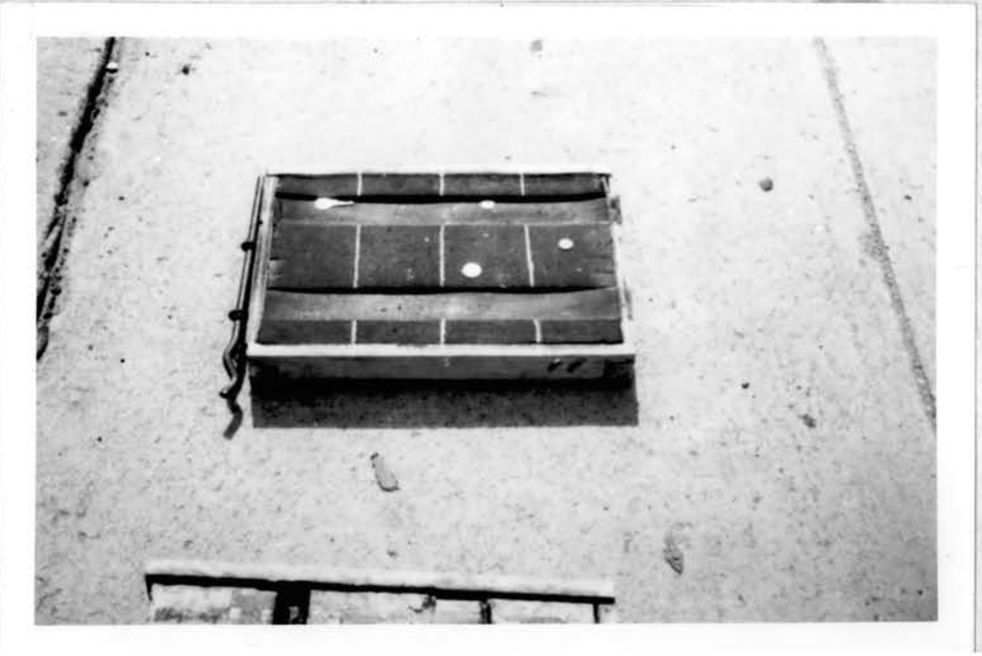












Bibliography

Periodicals: Hilts, H. E., "Highway Planning in Turkey", *Proceedings ASCE*, February, 1951.

Barber-Greene, "Bituminous Construction", *Handbook*, 1951.

Martin, J. Rogers, *Some Fundamental Principles in Relation to Asphaltic Concrete Pavement*, Volume 16, November, 1948.

THESIS TITLE: THE EFFECT OF IRON WHEELED CARTS ON FLEXIBLE AND RIGID HIGHWAY PAVEMENTS

NAME OF AUTHOR: ALI AVNI KIRKAGACLIOGLU

THESIS ADVISER: Professor J. Rogers Martin

The content and form have been checked and approved by the author and thesis adviser. "Instructions for Typing and Arranging the Thesis" are available in the Graduate School office. Changes or corrections in the thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

NAME OF TYPIST: Jerry Clendenin