in water did reach a state of failure. Table 9 also shows the number of cycles withstood up to the point of failure for all specimens. Most failures noted in the table were due to fracture of a specimen as it was handled after thawing. It seems quite apparent that gravel mixtures are more durable than more conventional mixtures of crushed rock.

While the evidence is not always conclusive, the following statements are suggested by the results of this investigation:

(1) Adequate stability can be obtained in a mix where the voids between interlocking coarse aggregate are filled with a plastic matrix of sheet asphalt.

(2) Such mixes are stable over a wide range of asphalt content. This fact permits use of sufficient asphalt to provide protection against stripping.

(3) Rounded gravel is a satisfactory aggregate in this type of mix.

(4) A square beam makes a good test specimen because the method of compaction can closely simulate ordinary construction practice in rolling.

(5) Lack of cohesion is accompanied by increased shrinkage.

No full-size test sections of this type of pavement have been laid in the field. Probably field experience would make it necessary to modify conclusions based wholly on laboratory tests, and the development of some sort of surface treatment might become desirable.

The investigation was carried out by H. H. Chen, H. K. Chang and R. K. Rippe[3] under the supervision of the authors.

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MOLDING SPECIMENS OF BITUMINOUS PAVING MIXTURES

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SYNOPSIS

This paper describes in brief the investigation conducted by the Texas Highway Department in 1939 to develop a molding machine and method which would produce satisfactory test specimens of bituminous-concrete paving mixtures. Nine machines were tested in the course of this investigation.

A method was evolved by which bituminous-concrete mixtures could be molded in the field laboratory, into cylindrical specimens 2 in. in height and 4 in. in diameter, having a density approximately equal to that obtained in a pavement produced from the mix and with approximately the same aggregate degradation.

The necessary equipment is a simple device to be used in conjunction with a hydraulic press found in most field laboratories. The molding principle employs gyratory shearing action of the mix at low initial pressures, allowing orientation of the aggregate particles. This is followed by direct compression at 1,590 psi. The procedure is most satisfactory and was used as a tentative method by the department from 1940 until 1946, when it was made standard and became a part of the specification requirements on all bituminous-paving mixtures.

This paper also describes a later adaptation of the gyratory molding method in producing specimens 4 in. in diameter and 8 in. in height for triaxial testing.

● Organized laboratory research by the Texas Highway Department in bituminous concrete was begun in 1939. The early stages of this research were devoted to the sound establishment of numerous fundamental concepts; to the development of adequate testing machines, equipment, and methods; and to the evolution of research tools, both mechanical and analytical. This phase of the work will never be completed, but progress has been made on an analysis of the effect of some of the variables upon the stability of the mix.

When testing a bituminous concrete mixture in order to ascertain the character of the pavement which will be produced from that mixture, it is essential that the physical characteristics of the specimen be as nearly identical as possible with the physical characteristics of the pavement.

A method was evolved by means of which

bituminous-concrete mixtures could be molded into cylindrical specimens 2 in. in height and 4 in. in diameter, having a density approximately equal to that obtained in a pavement produced from the mixture and with approximately the same aggregate degradation.

This method was used by the Texas Highway Department as a tentative method from 1940 until 1946, when it was incorporated in *Construction Bulletin C-14* and became a part of the specification requirements on all bituminous-paving mixtures. Several millions of tons of satisfactory paving mixtures have been designed and controlled through the use of this molding method.

MATERIALS

Servtex Limestone: This is a fairly dense limestone produced by the Servtex Materials Company from the Ogden Quarry at Ogden, Texas. The physical constants of this limestone are as follows:

Los Angeles Rattler S Grading Abrasion Value = 30.40 percent.

Size	Specific Gravity		Water Absorption
	Ssd.	Bulk	
			percent
½"–¼"	2 583	2 532	1.98
¼"–10 M	2.599	2 550	1.91
10 M–200 M	2.678	2 658	0 75
–200 M		2.690 (Chatelier)	

An average value of 2.578 was used for the bulk specific gravity of the aggregate as graded in this investigation. The unit weight (saturated, surface-dry and loose) was 107.57 lb. and the voidage content was 33.2 percent.

RC-2 Cut-back Asphalt: The cut-back was drawn from a 55-gal. drum equipped with a gate valve. Table 1, Column 1, shows the routine test results on a sample sent from the producer prior to delivery of the material. Columns 2 and 3 show results of tests made at two different times during this investigation to detect any changes caused by ageing. According to these results, no change occurred in the cut-back, because the variations in results are experimental variations, not being in the right direction to show age changes.

EQUIPMENT

Eight molding machines, which are described in detail under "Procedure," are included. Also, the Southwark-Emery (200,000-lb. capacity) hydraulic-compression machine is included, together with equipment incidental to: (1) preparation of aggregates, (2) preparation of mixes, (3) determination of specific gravity or density of the specimens, (4) extraction of specimens, (5) sieve analyses of extracted aggregate, and (6) similar procedures.

TABLE 1
ROUTINE TEST RESULTS OF RC-2 CUT-BACK ASPHALT
Lab. No. 39-146-B

Date	2-6-39	9-15-39	11-15-39
Tests			
Water, percent	Nil	Nil	Nil
Flash Point, T.O.C., deg. F.	110	—	—
Viscosity-Saybold Furol, 60 cc. at 122 F., secs	318	—	—
Specific Gravity at 77 F.	—	0.946	0.944
Pen. of Res. at 77 F., 100 g. 5 sec.	75	—	—
Ductility of Res. at 77 F., 5 cms. per min., cm.	111	—	—
Solubility of Res. in CCl_4, (percent)	99.90	—	—
Specific Gravity of Res. at 77 F.	—	—	1.008
Distillation			
I.B.P., (F.)	—	336	305
Percent off at 320 F.	—	0	1.5
Percent off at 347 F.	—	1.0	3.0
Percent off at 374 F.	—	4.5	9.0
Percent off at 437 F.	19.0	19.0	19.5
Percent off at 600 F.	28.5	29.0	29.0
Percent off at 680 F.	31.0	31.0	31.0
Asphalt Content (percent by Wt.)	—	74.4	74.5

PROCEDURE, TEST RESULTS, AND DISCUSSION

Preliminary Investigations and Decisions

It was necessary to make several preliminary investigations and decisions before the actual investigation of various methods of compacting specimens could be begun.

Molding Method and Evaluating Test for Control as Well as for Design—It was decided that the evaluating test to be evolved for asphaltic concrete should be equally adaptable to the control of the mix as well as to the design. A satisfactory test for design purposes might be useless as a mix-control test for a number of reasons. For example, an excellent procedure for preparing and testing a specimen for design purposes requiring a week to perform could not be used on the job for controlling a mix because of the time involved.

Since the preparation of a test specimen is an integral part of testing, the method of making the specimen must likewise be adapt-

able both to design and control conditions. This decision influenced the course of the investigation in several ways, as will be brought out in detail later.

Type of Asphaltic Mix, Constituents, and Proportions—The type of asphaltic concrete selected for use in this investigation was the Texas Highway Department's Item 309, Type M, Cut-back Asphaltic Concrete (dense-graded surface course), because it constituted the bulk of asphaltic concrete of ½-in. maximum size produced in the state, and only that part of an asphaltic mix which passes a ½-in. grizzly is used in making the old stability test.

Servtex limestone from the Ogden Quarry was used for the aggregate of the mix because it has a Los Angeles Rattler S Grading Abrasion value of about 30.4 percent (a value near the upper limit of the permissible wear at 35 percent). Therefore, the aggregate degradation occasioned by molding specimens containing another kind of aggregate would probably not be much greater than that of Servtex stone and in most cases would be less. Another justification for using Servtex stone was its use in large quantities for cut-back asphaltic-concrete production.

The aggregate grading adopted for the mix not only came within the specification limits for Item 309, Type M, but also conformed closely to the actual gradings in use at the pre-mix plants over the state. Since selection of the best type of machine from the several designed required the preparation of a great number of specimens, it was found expedient for saving time to stock the aggregate in the following sizes: ½-in., ⅜-in., ⅜-in., ¼-in., ¼-in., 10 M, and minus the 10 M. All the material of each size was blended. From time to time a control screen analysis was made on the prepared minus 10 M material to insure constant grading.

The screen analysis of the aggregate is shown in Table 2 as Design A. Note that the aggregate is on the 100 percent basis.

Since the RC-2 type of cut-back is used almost exclusively at pre-mix plants in the production of Item 309, Type M, it was selected. Having a large quantity of one producer's material on hand insured comparable test results as far as the binder was concerned. Furthermore, the RC-2 was subjected to the routine asphalt tests twice during its use to ascertain any possible change due to ageing.

The mix consisted of 85 percent aggregate on the absolute volume basis (93.9 percent by weight) and 15 percent RC-2. Thus with specific gravities of 2.578 for the aggregate and 0.944 for the RC-2 the percent by weight of RC-2 amounted to 6.1.

Individual Mix for Each Specimen—To determine whether or not a large mix could be used to furnish a number of specimens

TABLE 2
DESIGN A

Screen Size	Cumulative Weight in Grams	Percent	
		Individual	Cumulative
½-in.–⅜-in.	135.9	16.0	16.0
⅜-in.–¼-in.	288.8	18.0	34.0
¼-in.–10	577.5	34.0	68.0
10–20	617.4	4.7	72.7
20–30	655.7	4.5	77.2
30–40	690.5	4.1	81.3
40–50	715.1	2.9	84.2
50–60	729.5	1.7	85.9
60–80	744.0	1.7	87.6
80–100	752.5	1.0	88.6
100–200	775.4	2.7	91.3
–200	849.3	8.7	100.0
Total		100.0	
RC-2	904.5 (6.1 percent by weight of total mix)		
Less volatiles	11.3		
Final weight	893.2		

TABLE 3

Screen Size	Original Analysis	Extracted Analyses			
		No. 1	No. 2	No. 3	No. 4
	percent	*percent*			
½-in.–⅜-in.	16.0	14.4	17 1	16.7	16.0
⅜-in.–¼-in.	34.0	31.6	34.4	37.9	33.6
¼-in.–10	68.0	65.8	67.1	68.6	67.0
10 –20	72.7	72.4	73 3	74.0	73.2
20 –30	77.2	76.7	77.4	78.0	77.4
30 –40	81.3	80.7	81 3	81.8	81.3
40 –50	84.2	83.6	84.1	84.5	84.1
50 –60	85.9	85.1	85.4	85.7	85.4
60 –80	87.6	86.8	87.1	87.4	87.1
80 –100	88 6	88.6	88.3	88.4	88.0
100 –200	91.3	90.6	90.8	90.9	90.7
–200	100.0	100.0	100.0	100.0	100.0
RC-2	4.9	4.6	4.8	4.7	4.5

(weighing about 950 grams each) without introducing errors due to segregation, a mix weighing 12.78 lb. was prepared, mixed thoroughly, and carefully quartered. A sample of about 950 grams was taken from each quarter and extracted in the Rotarex to determine the amount of segregation. The results are shown in Table 3.

It is seen that the four specimens were quite uniform and checked very closely with the original analysis of the mix. However, every

precaution was taken in order to obtain such results; still there was enough discrepancy in the results to justify a better procedure to insure the accuracy desired in this investigation. It was decided to prepare each specimen separately.

Volatile content—A volatile content of 20 percent (volatiles = 100 percent) was selected as representing a workability optimum for rolling this mix in the field. It was realized that different volatile contents would represent an optimum workability for mixes containing another aggregate or another cut-back. It is not implied that the above value is recommended for standard procedure; it represents only the optimum workability for the mix used in this investigation.

The 20 percent volatile content used here was based on the volatile content of a 20-lb. mix (identical in every respect with an Item 309, Type M mix, used in part of this investigation containing 6.1 percent RC-2) which had been cured to a degree of workability at 90 F. deemed satisfactory for rolling. Engineers who were thoroughly familiar with the appearance and workability of this type of mix, were asked to determine the condition satisfactory for rolling. Thus in summary the constituents of the mix were as follows:

Aggregate = 849.3 grams (See Table 2)
Plus RC-2 = 904.5 grams (See A-2-d)
Volatiles off = 11.3 grams (See A-4)
Final weight = 893.2 grams

After the completion of this investigational project, a volatile content of 9.0 percent by weight (volatiles = 100 percent) just before rolling was found on the road (FAP 423-C3 and E3) in an item 309, Type M mix, consisting of RC-2 cut-back and Gifford-Hill crushed gravel and sand. Since the optimum workability would be expected at a lower volatile content in a gravel mix than in the same mix containing limestone, the value selected above is within reason.

Molding Temperature—In developing a new molding machine and molding method it was decided to mold specimens at a temperature comparable to that found on the road. It was also desirable that the temperature be easily and quickly attained for control testing. The temperature selected was 90 F., a temperature fairly representative of an average room temperature in the laboratory and the field laboratories during the asphaltic concrete construction period.

Desired Density of the Test Specimen—"Density," as hereinafter used, will signify the ratio of the total volume of the solids in the specimen to the total volume of the specimen. It may be obtained by dividing the actual specific gravity of the specimen (as determined by the method recommended in the Asphaltic Concrete Research Investigational Project 1) by the average specific gravity of the constituents of the specimen. Any effect on the calculated specific gravity of a specimen due to cut-back absorption by the aggregate was neglected in this investigation.

The density of cold-mix asphaltic-concrete pavements varies, not only for different types, or designs, but also for a single design, depending upon the aggregate and binder used. It is also known that the density of the pavement varies with time and traffic. Although apprised of these considerations, it was decided to select a specimen density of 94 percent to be produced by the molding method devised. This density is based on an average value found in asphaltic concrete pavements from about four months to about four years old, because for stability testing it is desirable that the specimen represent, not the density found in the pavement immediately after rolling, but the density found in the pavement after being aged and subjected to traffic.

Degradation—As the theoretical surface area is a function of particle size, the surface area of a degraded aggregate must always be greater than that of the aggregate before degradation. Thus surface area, within certain particle size limits, becomes a good relative measure of degradation. For the purpose of this investigation, degradation is expressed as the percentage increase of the surface area of coarse aggregate (½ to 10 M) as calculated on the basis of the surface area of coarse aggregate after degradation.

As there is little or no tendency for the faces of aggregate broken in molding to be coated with asphalt, the degradation value also expresses the percentage of uncoated coarse aggregate. This method for expressing degradation was developed in "Asphaltic Concrete Research Paper No. 2."

In another investigation it was found that

the highest degradation factor found on the road for moderately soft limestone was 16.4 percent. This was occasioned by a 10-ton roller. It is not likely that a density of 94 percent is found in cut-back asphaltic concrete pavements immediately after rolling. (There is no available data substantiating this statement nor disproving it, but it is a reasonable assumption.) Even so, when the pavement does reach a density of 94 percent due to ageing and the action of traffic, it is also reasonable to assume that the aggregate degradation does not increase to a great extent.

Preliminary investigations with the laboratory asphalt press employing the molding method then used in the field disclosed a degradation factor of about 46 percent for the machine and the same aggregate mentioned above (about three times that found in the road).

It was not likely that a molding machine could be devised which would mold a specimen quickly to a density found in the pavement after months of ageing and careful kneading by traffic and still produce as little degradation as is found in the pavement. In view of the above considerations, it was desirable that the machine selected would give less degradation than the laboratory press in compacting to the same degree. It was also desirable that the degradation produced approached as nearly as possible that found on the road.

Size and Shape of Specimen—In the past, cylindrical-shaped specimens have been used almost without exception in stability tests involving penetration, extrusion through an orifice, unconfined compression, or triaxial compression. Beam-shaped specimens, however, have been employed in making tensile and certain shearing strength tests. In order to correlate stability values (as now determined) for specimens molded on any new machine with stability values obtained for specimens molded on the laboratory asphalt press, it was necessary to design a machine with a cylindrically shaped mold to produce specimens 4 in. in diameter and 2 in. in thickness.

Since a molding device producing beam-shaped specimens suggested certain efficient compaction features, the idea of a beam shape was not abandoned. It was thought that stability tests developed later might require such a shape.

For either type of specimen a thickness of 2 in. was selected.

General Procedure

A set procedure was followed in preparing and curing the mix, determining the percent compaction of the specimen by measurement and by water displacement, and extracting the specimen for screen analysis of the degraded aggregate. In the tables of test results for the different machines only part of the test results accumulated during the entire investigation are shown. It was found expedient for this report to tabulate only part of the results to facilitate a comparative study of the different machines by the reader. This should be borne in mind, especially when studying the shorter tables. Also, results obtained for many experimental samples not discussed here aided materially in determining the course of the investigation.

Preparation of Mix—A specimen of Design A was prepared by thoroughly mixing 55.2 grams of RC-2 with 849.3 grams of graded stone (see Table 2). A small pan ($8\frac{1}{2}$ in. in diameter at top, $7\frac{1}{2}$ in. in diameter at bottom and $2\frac{1}{4}$ in. deep) and trowel were tared on a 10-lb. torsion balance sensitive to 0.1 gram, and the different sizes of stone were then weighed into the pan according to the weights shown in Table 2. After blending the stone, the RC-2 was added and mixed thoroughly at room temperature with the stone.

Curing the Mix—After preparing the mix, it was placed (still in the pan) in the oven at 250 F. and allowed to remain until almost 80 percent of the volatiles had been removed (as determined by several weighings). When the mix cooled, it was weighed again to check the desired volatile content of 20 percent (11.3 grams off, 2.8 grams remaining) to within 0.3 gram. After allowing the specimen to cool further to the molding temperature, it was ready for molding.

Method of Determining Density—Percent compaction, or density, of a specimen equals the ratio of its solid volume to the solid volume plus all voids (internal and surface) multiplied by 100. If the second volume is determined by water displacement (as in a specific

gravity determination), the surface voids of the specimen are excluded.

After molding the specimen, it was calipered in four places for an average height. This measurement was made for use in calculating the densities of specimens, or their percent compaction, by the ratio of the solid volume to the measured volume.

The density of a molded specimen obtained in this manner equals the ratio of the specimen's solid volume to its volume obtained by water displacement in the specific gravity determination. The method for determining specific gravity by a special paraffin coat on the specimen is described in the Asphaltic Concrete Research Investigational Project No. 1. Subtracting the density obtained by measurement from that obtained by water displacement gave the surface voids in a specimen.

Sieve Analysis of Extracted Aggregate—After making specific gravity determinations on the specimens, the aggregate was extracted by carbon tetrachloride in the Rotarex, dried, and then screened for 15 minutes in an automatic shaker. An ash determination was made on an aliquot part of the extracted asphalt and included in the total aggregate. Screen analysis data on aggregate extracted from a molded specimen was used in calculating the degradation value.

MOLDING MACHINES AND METHODS

In the following arrangement of molding machines and molding methods the evolution of the best type of machine can be seen. Usually the performance of one machine (whether good or bad) suggested the use of another machine employing variations in similar principles of molding, or suggested the need for designing a new machine utilizing principles worthy of trial.

Extractions were not made on a number of specimens for supplying degradation data because the densities of those specimens were too far below the desired 94 percent density to warrant the degradation determination.

Machine 1 (The Laboratory Asphalt Press)

Description and Operation—The asphalt press is the same type of hydraulic press as the old machine described in the 1936 Texas Highway Tentative Bulletin C-9 with the exception of a few minor design changes. Referring to Figure 1, the press consists of a reaction head (1), a round platen (2), a hydraulic jack with one actuating plunger (3), a base (4), a 10,000-psi. high-pressure gage measuring the fluid pressure on the piston (5), an automatic high-pressure valve and a recording pressure gage (7). The last two accessories are used in stability tests on molded specimens, but not in the molding operation.

Molding tools consist of a molding cylinder 4.01 in. in diameter and 4 in. in height (8), a molding base plate (9), a 4-in.-diameter flat compression ram and a 4-in.-diameter corrugated compression ram—see Figure 1(a)—and a 3-in. extractor ring, not shown in either illustration.

The old standard-molding procedure for hot mixes consists of molding a specimen at 325 F. with the corrugated ram and molding cylinder at 212 F. (accomplished by heating in a boiling water bath) at 3,125 psi. The pressure is released, the ram is turned 180 F., and the same pressure is reapplied. A flat ram (at 212 F.) is substituted for the corrugated ram, and a pressure of 3125 psi. is again applied. Extraction of the molded specimen from the molding cylinder is accomplished by placing an extractor ring between the cylinder and platen and forcing the specimen out by means of the flat ram.

Paper shims placed at the top and bottom of the mix prevents the specimen sticking to the base plate and ram. As shown in Figure 1(a), the bottom of the corrugated ram has a flat section and a concave section. This shape was intended to impart a transverse motion to the mix during compression. By turning the ram 180 deg., the transverse motion was imparted in the oppsoite direction.

Since the gage recorded fluid pressure on the jack piston, it was necessary to calculate the pressure on the specimen. This was done by multiplying the gage reading in pounds per square inch by the ratio of the piston area to the specimen area. Example:

$$4{,}909 \text{ psi. (Gage Rdy.)} \times \frac{8 \text{ sq. in. (Piston Area)}}{12.5664 \text{ sq. in. (Specimen Area)}} = 3{,}125 \text{ psi. on the specimen}$$

Procedure—Specimens of Design A were molded in the laboratory asphalt press according to the old standard method and

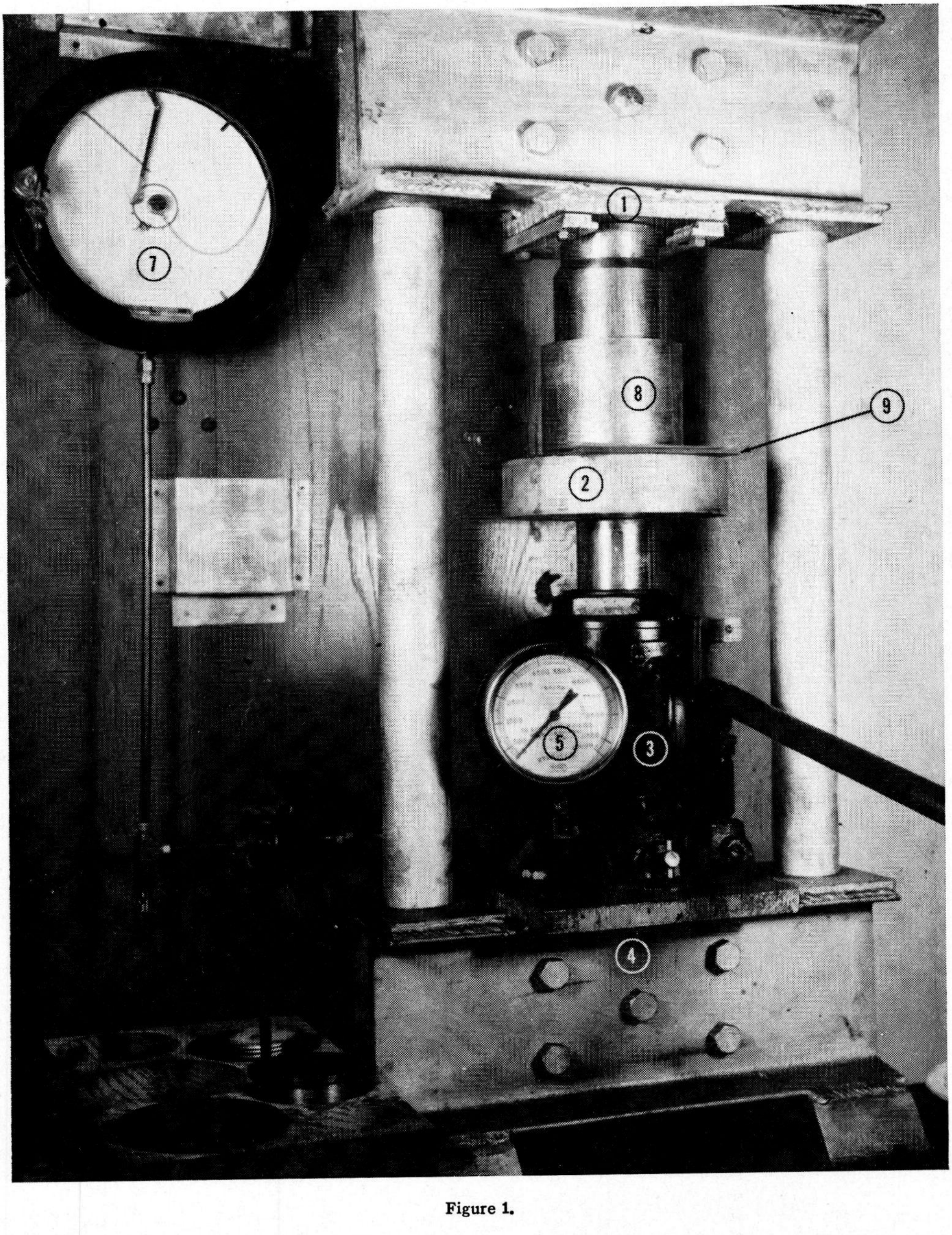

Figure 1.

according to modifications of that method involving changes of compressive load and type of ram used.

Discussion—In Table 4, the specimens molded by the flat ram are listed in one group, and those molded by both the flat and corrugated rams are listed in another. In each group the specimens are arranged in order of increasing density, percent solids, or percent compaction. It will be noted that the densities obtained increased with the compressive load applied and that the height of sample meas-

urements decreased with the load applied. While accurate average-height measurements were made difficult by the rough texture of the specimens (the accuracy obtained was about ±0.01 in.), such measurements gave a rough check on the specific gravity determinations. Results for Specimens 6–17 and 10–21 were not averaged together in order to show the inappreciable effect on degradation by varying the rate of load application.

Figure 1(a).

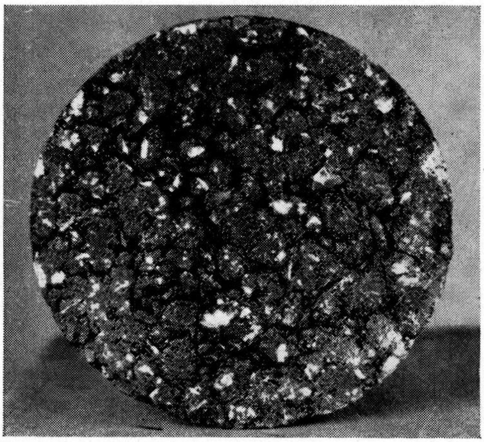

Figure 2.

The surface-void values should have decreased with increase in densities of specimens; their apparently not doing so is attributed to inaccuracies of height measurement. Densities as obtained by the ratio of measured volume to the solid volume increase with the load but not in an amount as measured to give quite the correct surface-void values.

The rate of load application was varied for Specimens 6 and 17 and 10 and 21 with no effect.

Extracted aggregate from some of the specimens of 94 percent density or greater was accurately screened to provide data for calculating the degradation values. As would be expected, the amount of degradation increased with the compressive load. At the same compressive load a greater degradation was occasioned by the flat ram alone. Compare Specimen 40 with Specimens 6 and 10.

Figure 2 shows the top surface of Specimen 17 molded at 2,546 psi. with the flat ram (see Table 4). Figure 3 shows the top surface of Specimen 41 molded to greater density with both rams at 2,546 psi. on the specimen (see Table 4). Note that the aggregate in this specimen is visibly more degraded than that of Specimen 17.

Machine 2 (Southwark-Emery 200,000-lb. Hydraulic-Compression Machine

Description and Operation—In order to ascertain the effect on aggregate degradation of molding in a manner identical with that employed by the laboratory asphalt press but at a much slower rate, several specimens were molded on Machine 2, see Figure 4.

Specimens were molded with the same molding cylinder and flat ram used with the laboratory asphalt press. Figure 4(a) shows the molding assembly in place under the movable head of the compression machine. The calipers shown in the illustration are used for determining the thickness of the molded specimen and also to measure the rate of consolidation.

Procedure—Specimens were molded at pressures between 2000 and 4000 psi. at a consolidation rate of 0.0805 in. per min.

Discussion—Since cut-back behaves more nearly like a viscous liquid than a plastic at 90 F., it was thought that a low rate of load application would permit better orientation of the aggregate particles during the early stages

of continuous increasing compression and thereby diminish the amount of aggregate degradation during the later stages. A viscous liquid flows continuously under a minimum shearing stress, whereas a plastic requires for continuous flow a shearing stress in excess of a definite stress to produce initial flow.

hammer). The number of blows per layer was varied from 200 to 400.

Discussion—Table 6 shows the effect of the number of Proctor hammer blows on the density of specimens. Specimens 15, 19, and 43 were not averaged, because the different molding temperatures apparently had some

TABLE 4
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 1

Speci-men No.	Molding Method					Specific Gravity	Compac-tion (by Sp. G.)	Height of Sample	Compac-tion (by Vol.)	Surface Voids	Degra-dation Factor
	Mold-ing Temp.	Pressure: Gage	Pressure: On specimen	Ram	Rate of load appl.						
	F.	*psi.*	*psi.*	*type*			*percent*	*in.*	*percent*	*percent*	*percent*
9	90	3000	1910	Flat	Stroke/5s	2.191	91.67	2.02	89.32	2.35	—
6	90	4000	2546	Flat	Stroke/s	2.247	94.04	1.96	92.06	1.98	33.34
17	90	4000	2546	Flat	Stroke/s	2.239	93.70	1.97	91.59	2.11	29.93
10	90	4000	2546	Flat	Stroke/5s	2.261	94.61	1.96	92.06	2.55	34.97
21	90	4000	2546	Flat	Stroke/5s	2.235	93.53	1.96	92.06	1.47	32.42
5	90	4500	2856	Flat	Stroke/s	2.275	95.22	1.94	93.01	2.21	—
2	90	5000	3183	Flat	Stroke/s	2.286	95.69	1.93	93.49	2.20	—
40	90	4000	2546	Both Rams	Stroke/s	2.285	95.63	1.91	94.47	1.16	41.15
41	90	4000	2546	Both Rams	Stroke/s	2.301	96.29	1.90	94.96	1.33	—
36	85	4909	3125	Both Rams	Stroke/s	2.311	96.72	1.89	95.47	1.25	45.24
39	90	4909	3125	Both Rams	Stroke/s	2.308	96.60	1.88	95.97	1.88	44.70

Molding at a very slow rate (0.0805 in. per min.), however, on the Southwark-Emery machine did not produce the desired low degradation factor. Comparing degradation factors of specimens molded on the above machine with degradation factors of specimens molded with the laboratory asphalt press (flat ram only) to comparable density indicates the irrelevancy of molding rates. Compare Specimens 50 and 53 in Table 5 with the averages of Specimens 6 to 17 and 10 and 21 in Table 4.

The above comparison is made with the laboratory asphalt press employing the flat ram only, because a flat ram was used with the Southwark-Emery machine.

Figure 5 shows the top surface of Specimen A-44 molded at 3,072 psi. on the Specimen (see Table 5).

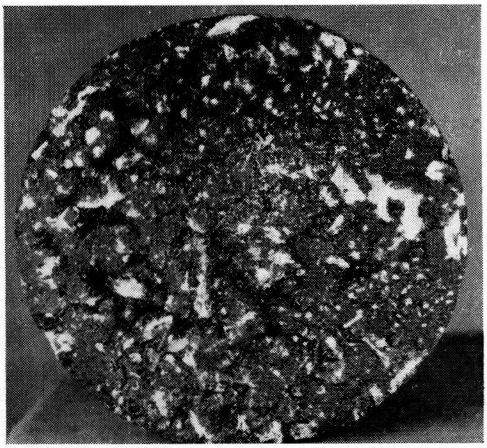

Figure 3.

Machine 3 (Proctor Soil-Compaction Machine)

Description and Operation—The Proctor Compaction Machine is familiar to everyone and will not be described here. It is shown in Figure 6.

Procedure—Specimens were molded by placing three layers of the mix in the mold and subjecting each layer to the same number of hammer blows (using a 12-in. drop of the

effect on the extent of compaction, *i.e.*, the amount was proportional to the molding temperature.

Specimens 15 and 19 were extracted for degradation data since they alone represented densities of at least 94 percent. Note that the degradation factors are about 7 percent less than those obtained with the laboratory press molding to comparable densities. The three layers comprising the specimen were clearly

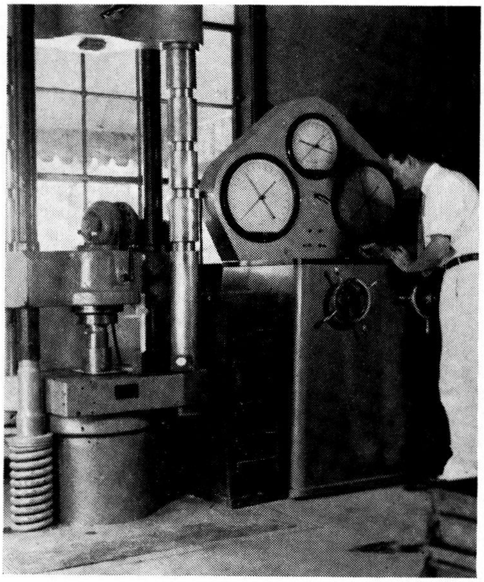

Figure 4.

demarked, representing inefficient cohesion between layers and, therefore, two planes of weakness.

Figure 7 shows the top surface of Specimen 43 subjected to 400 blows per layer (see Table 6). Note the aggregate crushed by the hammer action.

Machine No. 4 (P.R.A. Vibratory Machine)

Description and Operation—This machine was designed by the Construction Division and constructed by the Equipment Division. It is a simplification of the BPR vibratory machine for determining the compactibility of aggregate. The BPR machine is described in *Public Roads,* Vol. 20, No. 3, May 1939 [*q.v.*]. Figure 8 shows the assembled machine.

Quoting from *Public Roads:*

"The machine consists essentially of a floating table that is made to move vertically in periodic motion by rotating eccentric masses rigidly connected to its lower surface. The table is a steel plate 13 by 24 in. in size and

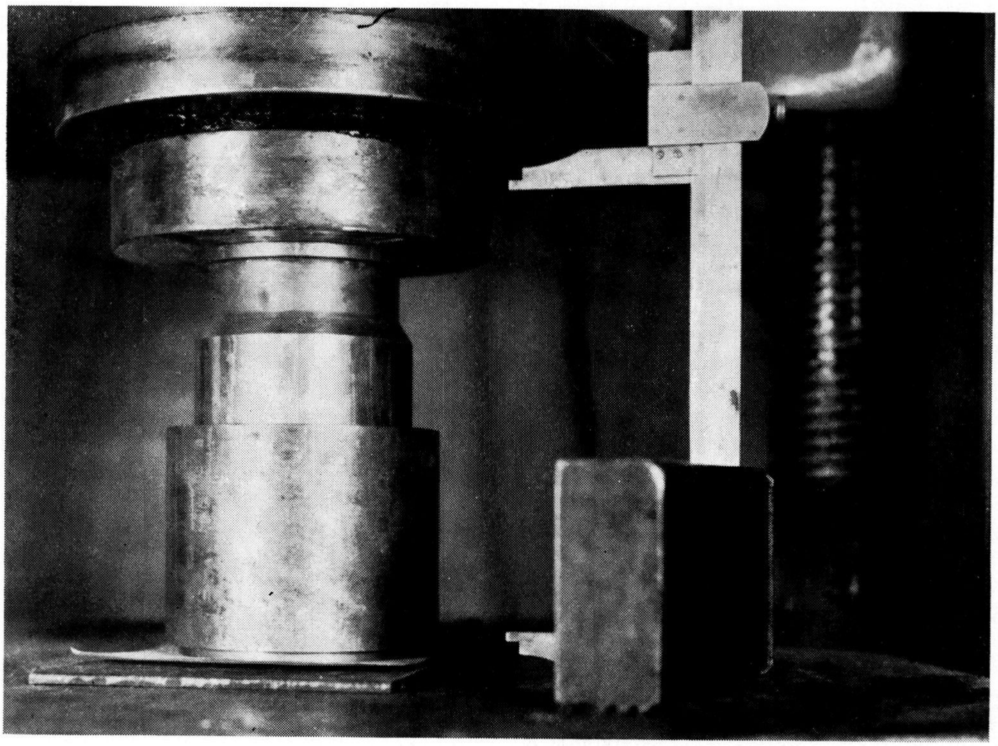

Figure 4(a).

TABLE 5
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 2

Specimen No.	Molding Method			Specific Gravity	Compaction by Spec. Gr.	Height of Sample	Compaction by Volume	Surface Voids	Degradation Factor
	Molding Temperature	Pres. on the Specimen	Rate of Deformation						
	F.	*psi.*	*in. per min.*		*percent*	*in.*	*percent*	*percent*	*percent*
49	90	2000	0.0805	2.199	92.04	2.02	89.54	2.50	33.53
50	90	3000	0.0805	2.238	93.67	1.95	92.53	1.14	39.12
26	90	3072	0.0805	2.253	94.30	1.94	93.01	1.29	38.00
44	85	3072	0.0805	2.255	94.38	1.94	93.01	1.37	35.79
53	90	3072	0.1610	2.253	94.30	1.95	92.53	1.77	37.54
37	90	3429	0.0805	2.260	94.56	1.97	91.59	2.97	38.19
52	90	4000	0.0805	2.273	95.11	1.92	93.97	1.14	39.08

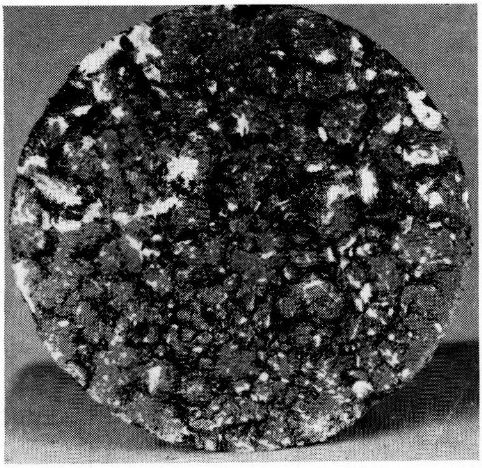

Figure 5.

$\frac{3}{4}$-in. thick. It is supported at each corner by a helical spring through which there is a vertical guidepost on which the table slides.

"On the lower surface of the table, mounted parallel to the long axis of the plate, are two shafts running in ball bearings and geared to rotate at the same speed but in opposite directions. Four steel blocks of equal size and weight are symmetrically mounted at the ends of the two shafts, one at each end of each shaft. The size of these blocks and the speed at which they are rotated determine the magnitude of the unbalanced force. Since the two shafts rotate in opposite directions, only vertical accelerations are imparted to the system."

The weighted shafts are rotated at 4,300 rpm. by a $\frac{3}{4}$-horsepower electric motor with a single speed, V-belt drive. This is not the motor shown in Figure 8.

Referring to Figure 8(b): "The assembly

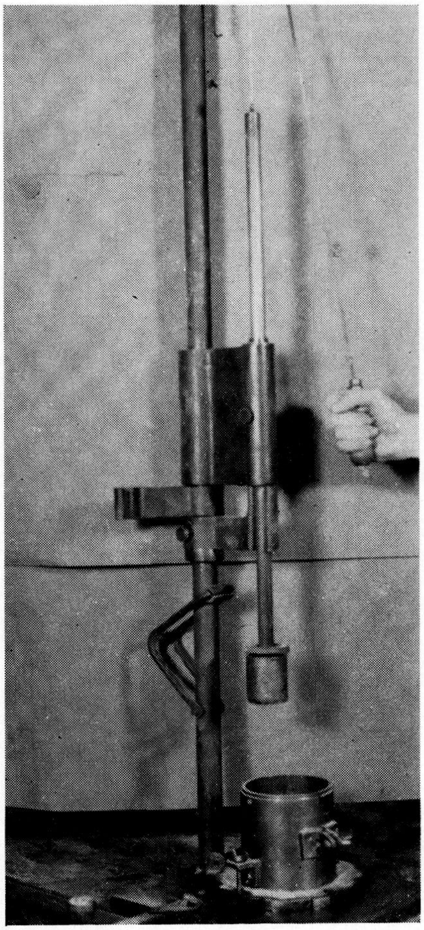

Figure 6.

for holding the aggregate to be tested is bolted to the top of the vibrating plate or table. Its essential parts are a base plate (1), and bottom plunger (2), bolted to the table, a 4.01-in.-

diameter cylinder (3), fitting over the bottom plunger and resting on a rubber support (4), and a 4-in.-diameter top plunger (5), which rests on the test material in the cylinder.

"A micrometer dial mounted on a suitable base is used in conjunction with a series of calibrated test gage blocks to measure the thickness of the compacted specimen without removing it from the cylinder."

TABLE 6
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 3

Specimen No.	Molding Method			Specific Gravity	Compaction by Spec. Gr.	Height of Sample	Compaction by Volume	Surface Voids	Degradation Factor
	Molding Temperature	Blows per Layer	Total Blows						
	F.	*no.*	*no.*		*percent*	*in.*	*percent*	*percent*	*percent*
3	90	200	600	2.173	90.92	2.05	88.45	2.47	—
7	90	250	750	2.195	91.87	2.04	88.89	2.98	—
14	92	300	900	2.221	92.94	1.99	91.12	1.82	—
15	95	400	1200	2.253	94.27	1.94	93.47	0.80	28.67
19	90	400	1200	2.248	94.08	1.97	92.05	2.03	26.86
43	85	400	1200	2.195	91.85	2.01	90.21	1.64	—

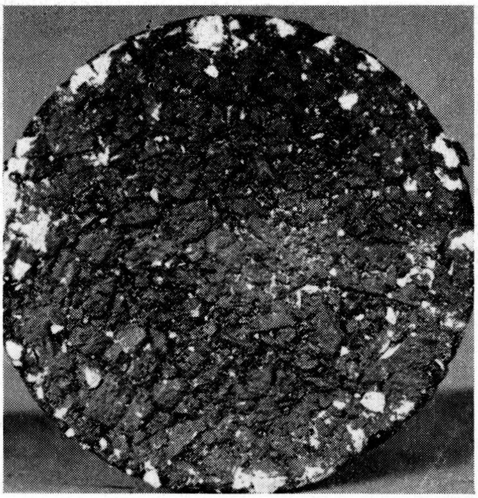

Figure 7.

A top plunger imposes a dead load of 1.80 psi. on the sample to be compacted. "Both the top and bottom plungers have sufficient clearance within the cylinder to allow free vertical movement during vibration." The top cylinder is fitted with three bronze guide strips (6) to maintain it in a position parallel to the axis of the cylinder.

Preparatory to molding a specimen, a paper shim is placed on the bottom plunger to protect its face. The molding cylinder is then slipped over the bottom plunger, and the mix to be molded is carefully placed in the cylinder to avoid segregation. After covering the top of the mix with a paper shim, the top plunger is inserted. The motor is started and allowed to run until the desired amount of vibration has occurred.

Procedure—Specimens were molded at various vibration times to establish the minimum time (if any) giving 94 percent compaction.

Discussion—The effect of vibration time on specimen density is shown in Table 7. Above a 15-min. vibration time there was no appreciable increase in density. Since a 30-min. vibration time failed to give a density of at least 94 percent, longer periods of vibration were not employed as the molding time would be extended beyond a practical limit.

Extractions for degradation data were not made since none of the specimens were of the desired density.

Figure 9 shows the top surface of Specimen 51 which was vibrated for 15-min. (see Table 7). Note the more open texture of this specimen as compared with the preceding photographs of specimens of greater density. Note also the small amount of degradation.

Machine 5 (Pneumatic Roller)

Description and Operation—This machine, see Figures 10 through 10(d), was designed and constructed by a district of the Texas Highway Department. It was not constructed for use in this investigation. Since it was on hand, however, it was requested that the machine be given a trial for molding specimens.

Figures 10 and 10(a) show the essential parts of the machine. A roller (1), 6 in. wide

and 2 in. in diameter, compacts a specimen to 6 by 8 by approximately $\frac{3}{4}$ in. thick con-

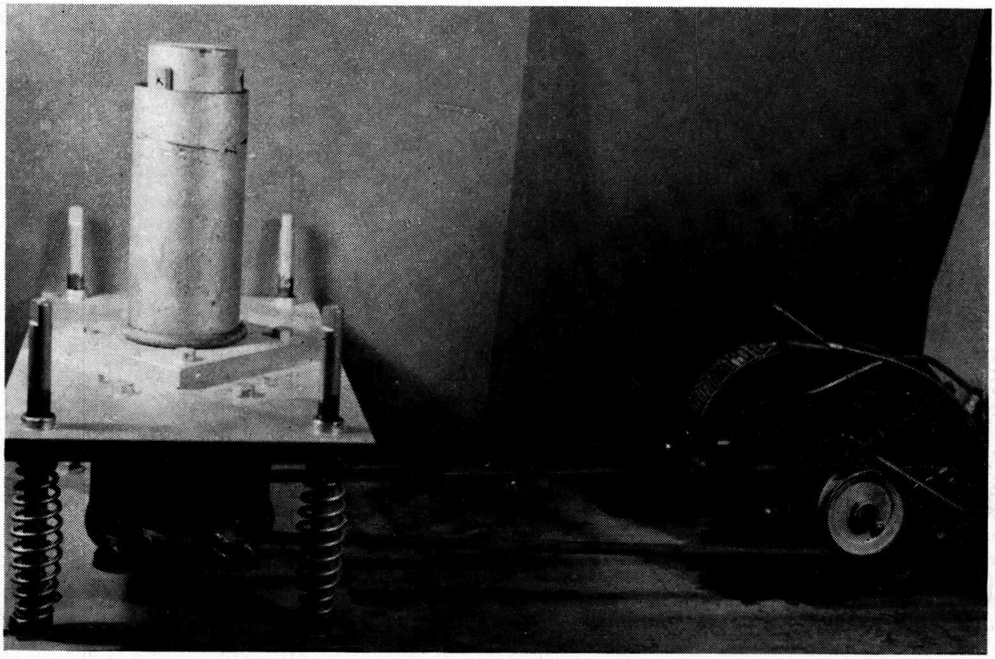

Figure 8.

tained in the molding pen (2). A variable vertical load is applied to the roller by means of a motor-driven air compressor (3 in Figure 10) and the pressure regulator (4). A horizontal reciprocating motion is given to the roller by means of a motor (5) just visible under the table in Figure 10(a) and the cam arrangement (6) shown in the same illustration.

An end-view of the machine is shown in Figure 10(b). Figures 10(c) and (d) show close-ups of the roller and molding pan with a sample in place.

To compact a specimen about 3,100 grams of the mix were placed in the molding pan (2) and carefully leveled off to prevent segregation. The air compressor (3) was started with the pressure regulator (4) set at 40 psi.

The roller (1) was then set in horizontal motion by closing the switch (7) shown in Figure 10. The mix was rolled until maximum compaction was obtained at the pressure designated.

Since the roller pushed some of the mix out at each end of the molding pan shown in

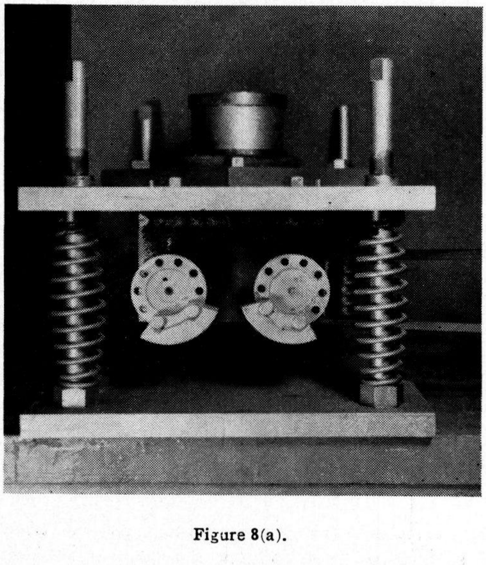

Figure 8(a).

these illustrations, a pan having higher walls was constructed and tried, but it was still

impossible to prevent some of the mix from being forced out of the pan.

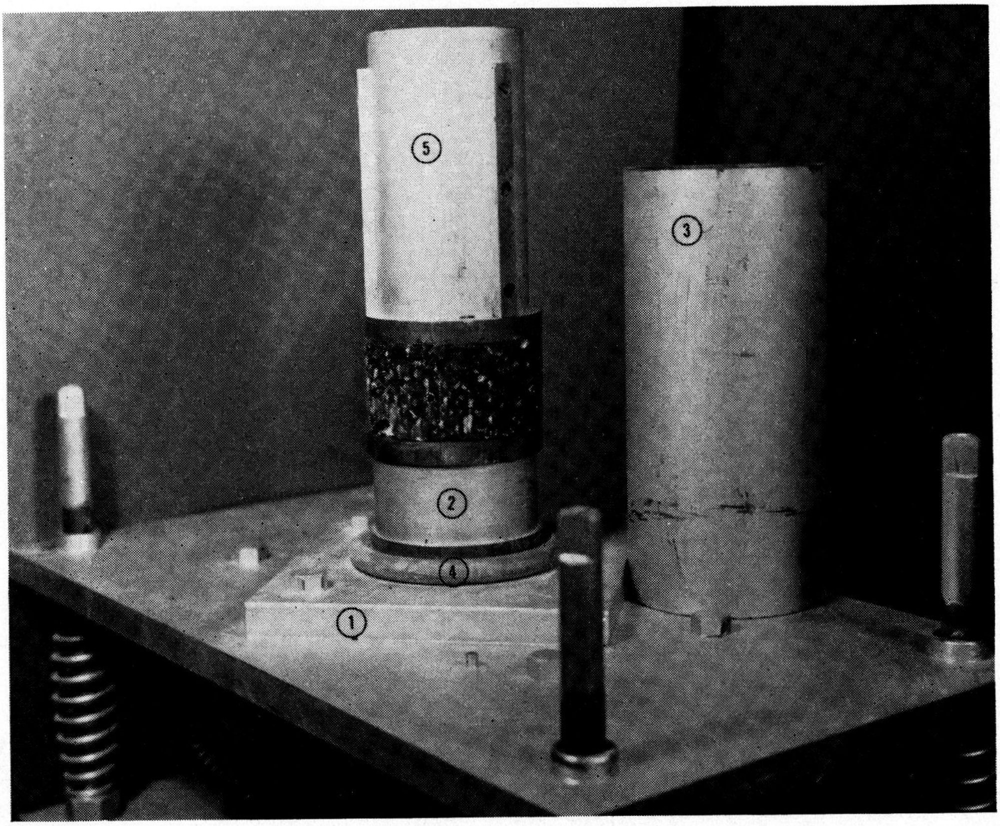

Figure 8(b).

TABLE 7
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 4

Specimen No.	Molding Method		Specific Gravity	Compaction by Spec. Gr.	Height of Sample	Compaction by Volume	Surface Voids	Degradation Factor
	Molding Temperature	Vibration Time						
	F.	*min.*		*percent*	*in.*	*percent*	*percent*	*percent*
4	90	15	2.148	89.88	2.12	85.11	4.77	—
51	90	15	2.135	89.36	2.14	84.31	5.05	—
20	90	20	2.030	84.91	2.29	78.79	6.12	—
22	92	20	2.130	89.14	2.10	85.92	3.22	—
47	90	20	2.087	87.34	2.22	81.46	5.88	—
8	90	25	2.148	89.89	2.17	83.15	6.74	—
48	90	30	2.109	88.24	2.15	84.12	4.12	—
63	90	30	2.192	91.73	2.06	87.59	4.14	—

Discussion—This machine was not at all satisfactory. In addition to the mix being forced out of the pan during the reciprocating action of the roller producing specimens of nonuniform thickness, the compacted part of the mix remaining in the pan after molding was badly segregated with the coarse aggregate on top and the fine material on the bottom.

Since a number of extracted road samples

of Item 309, Type L, taken from the road after rolling showed practically no segregation from the bladed mix, it was decided to permit no segregation in a desirable molding machine.

In view of the foregoing objections no test results were made upon molded specimens, and the machine was eliminated from further investigation.

Machine 6 (Conical Roller)

Description and Operations—Figure 11 shows the machine in operation. The sample is contained in the molding cylinder (1) under a constant load of 100 pounds furnished by four sacks of lead shot (4). It is compressed by rotating the brace (3), at the end of which is a conical-shaped foot (2). The brace pivots through the framework (5). The upright bolts welded to the channel iron base hold the molding cylinder in place.

The molding-cylinder diameter is 4.02 in. and the cylinder 4 in. in height. The conical-shaped foot (2) shown in Figures 11(a) and (b) consists of a 4-in. steel cone welded to a piece of pipe ½ in. in diameter and 6.0 in. long. The face of the cone has a 1 :4 slope. Several pieces of pipe welded together form the brace for rotating the foot.

Figure 11(a) shows a molded sample in place with the molding cylinder removed. Several rubber gaskets placed in the bottom of the molding cylinder and one placed on top of the material to be molded permits better compaction of the specimen. Presence of the gaskets also provides enough friction to prevent rotation of the specimen within the cylinder during molding.

This machine was designed to compact a specimen in a manner similar to that in which pavement is compacted by a roller. As compaction progresses, the area of contact between the foot and specimen decreases, so that the instantaneous vertical unit load is continuously increasing. Since at any instant during rotation of the foot, only part of the specimen volume is under vertical load, that part of the volume is sheared vertically with respect to the remainder of the specimen.

The crimp foot shown in Figure 11(b) is an alternate shape of foot designed to produce greater shear than the cone foot.

Preparatory to molding a specimen, the mix is carefully placed in the molding cylinder on top of several rubber gaskets and then covered with a single rubber gasket. The load, brace, and foot are then lowered onto the specimen. The brace is then rotated the desired number of times.

Procedure—Specimens were molded on one side under a total load of 100 lb. at various revolutions of the compression foot. They were then turned over and subjected to the same load and the same number of revolutions. Both the conical and the crimped types of foot were used.

Discussion—Four specimens were molded on Machine 6 under 100 lb. total load at various degrees of shearing action, *i.e.*, various numbers of compression foot revolutions, see Table 8. Two of the four specimens were molded with the conical-shaped foot, one with both the conical and crimped foot and another with the crimped foot alone. The specimen density obtained was proportional to the amount of shearing action exerted on the specimen. Increasing the number of revolutions of the conical foot, or using the crimped foot alone, increased the amount of shearing action on the specimen. Since a density of at least 94 percent was not obtained by any molding method, no extractions were made for degradation data.

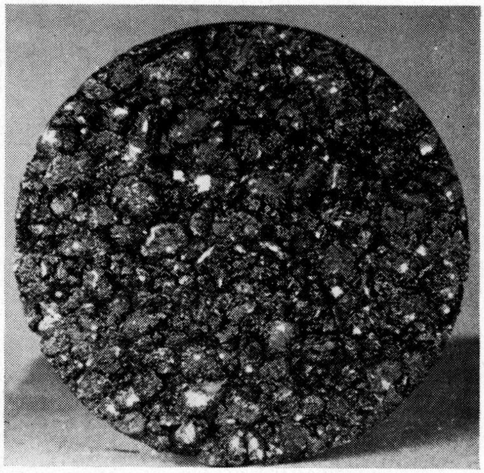

Figure 9.

Specimens 31 and 35 were of such irregular height (top and bottom of the specimens not parallel, due to the type of molding action) that height measurements were meaningless.

The irregularity and lack of parallelism in the top and bottom specimen surfaces was the main objection to this molding machine, as the desired density may have been obtained by increasing the vertical load.

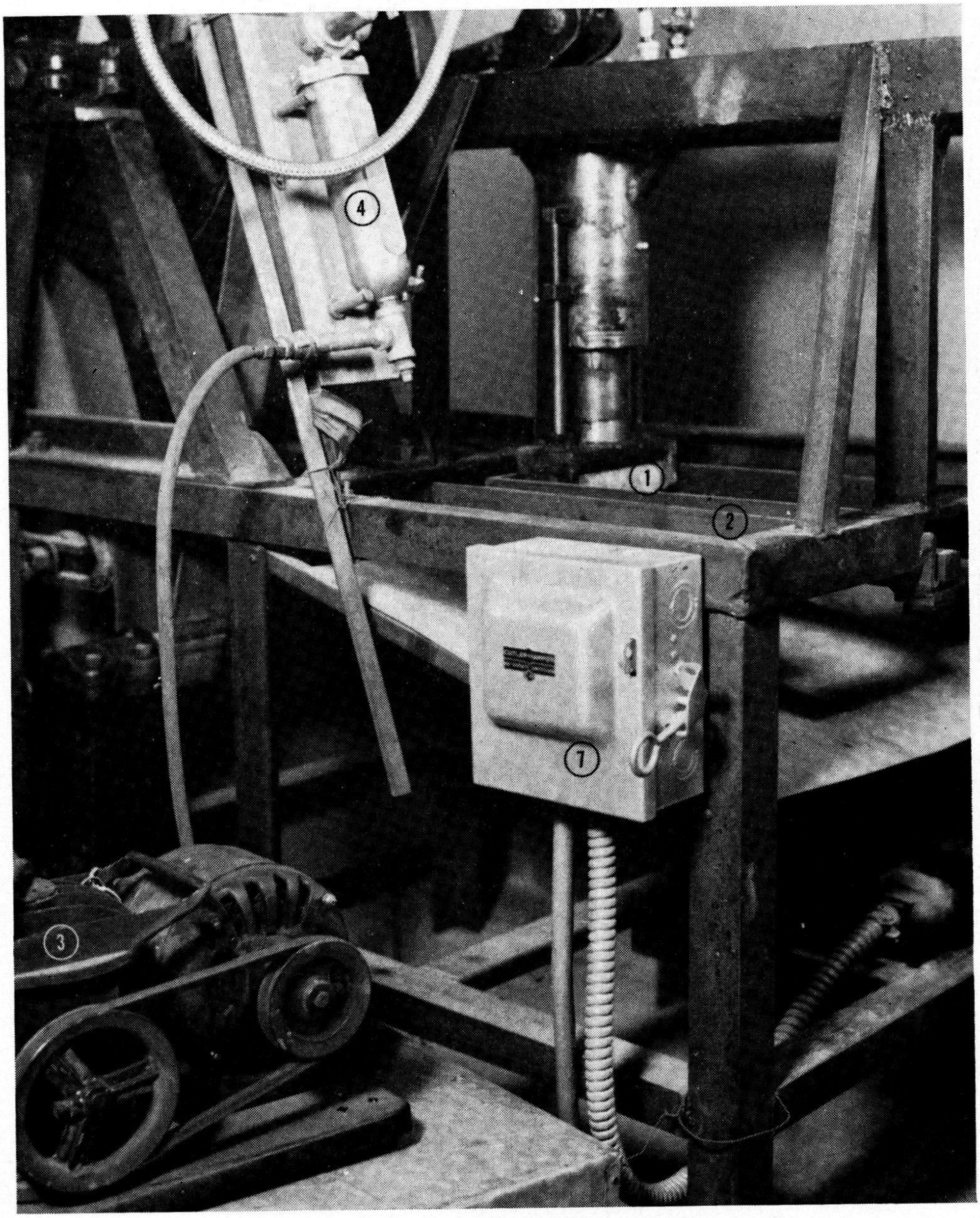

Figure 10.

The unit pressure on the specimen is recorded as variable in Table 8, because as compaction of a specimen progressed, a diminishing amount of the molding foot area was in contact with the specimen. Thus, the

unit load on the specimen increased during the molding operation.

Figure 12 shows the top surface of Specimen 29 molded with 800 revolutions of the conical foot (see Table 8).

Machine 7 (Horizontal Shear in a Cylinder)

Description and Operation—The unsatisfactory performance of Machine 6 led to the design and construction of Machine 7 (see Figure 13) which compacts a specimen by shearing it horizontally under a constant vertical load, the entire volume of the specimen being subjected to the vertical load during the shearing action.

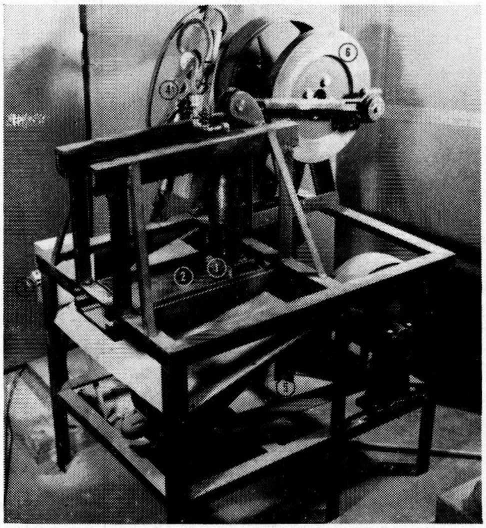

Figure 10(a).

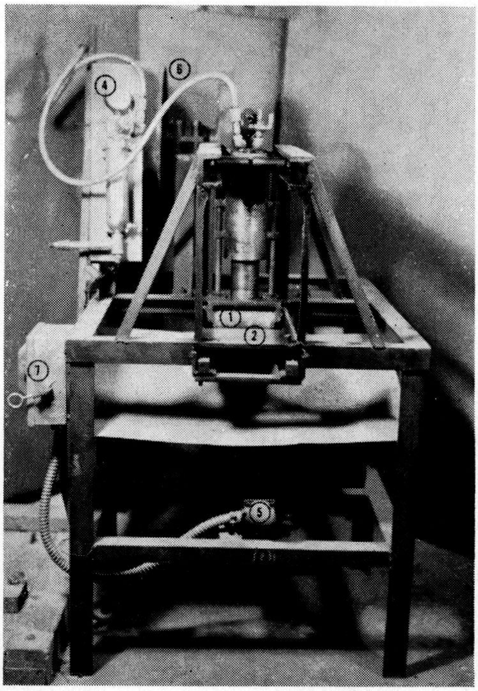

Figure 10(b).

The operation principle of Machine 7 differs from that of Machine 6 in that the entire specimen volume is consolidated at the same time during application of the shearing action. There is no vertical shearing of part of the specimen volume with respect to the rest of the volume. Another difference is the tendency of Machine 7 to shear the entire top part of a specimen with respect to the bottom part, since the compression ram is in contact with the entire top surface of the specimen. The latter difference produces a more severe shearing action than is obtained by Machine 6.

Figure 13 shows the machine assembled for operation. The operator molds a specimen

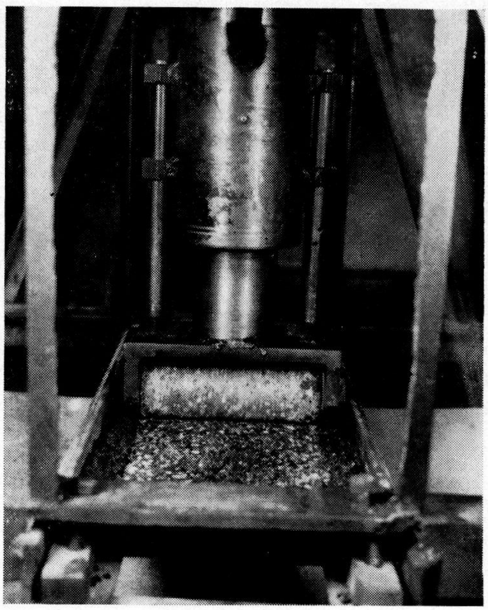

Figure 10(c).

by oscillating the ram handle in a horizontal plane a given number of times while the specimen is under a constant load of 80 psi. The machine consists of the following parts: a molding cylinder 4.035 in. in diameter and 4 in. in height (1), a 4-in.-diameter molding ram (2) with handles, a 6.4-ft. counterweighted lever arm (3). Figure 13(a) shows a molded specimen in place with the molding cylinder and load removed.

The working faces of the ram and the base—Figure 13(b)—are provided with detachable scarified lead faces fastened by friction joints. These roughened shims prevent slippage of the specimen during horizontal shear. Later, another pair of handles was welded to the ram at right angles to the existing pair. The molding procedure was varied for the four-armed ram by raising vertically each arm of the ram in succession a given number of times while the specimen was being subjected to the constant load.

The yolk supporting the lever arm (3) is pivoted to the base to facilitate placement of the bearing point on the ram. The lever arm is pivoted to the yolk, and the pivot-point acts as the fulcrum for the system during the molding operation.

A constant load is supplied by sacks of lead shot.

Procedure—Specimens were molded on this machine under several compressive loads and at various revolutions of the compression foot.

Discussion—Table 9 shows specimens molded on Machine 7 arranged in order of increasing density. Since several specimens were of about 94 percent density with degradation factors less than those obtained with the other machines molding to equal density' preliminary considerations seemed to indicate that Machine 7 had possibilities. Closer inspection, however, revealed that the center area of the specimen was not compacted as well as the rest of the specimen, see Figure 14.

This, of course, was due to the smaller amount of movement under the center portion of the compression foot (theoretically, there is no movement of material under the geometric center of the foot during oscillation).

To verify the above conclusion a specimen molded on Machine 7 to 93.56 percent density

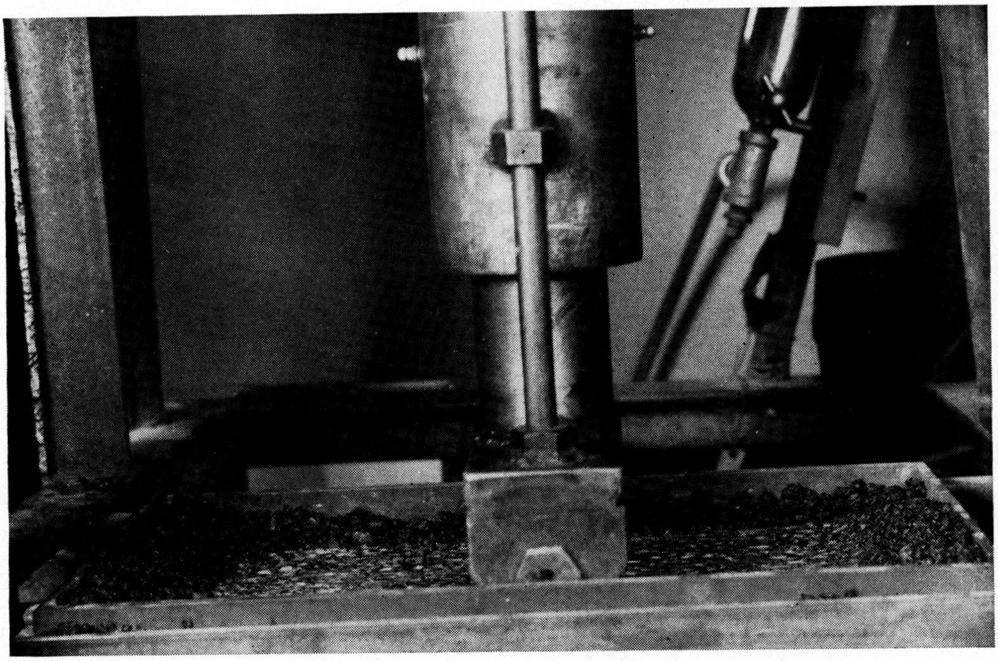

Figure 10(d).

was chilled to 0 F. and then turned on an emery wheel until a 2½-in.-diameter cylinder was obtained from the center of the original specimen. The percent compaction of the cone (as determined by water displacement) was 91.73 percent or 1.83 percent less than that of the original specimen. By calculation, the density of the rest of the specimen was 94.91 percent.

Height of specimen measurements designated in Table 9 by the numbers 45 and 18 were not accurate, because the top and bottom of the compacted specimens were not quite parallel. For that reason *percent compaction*

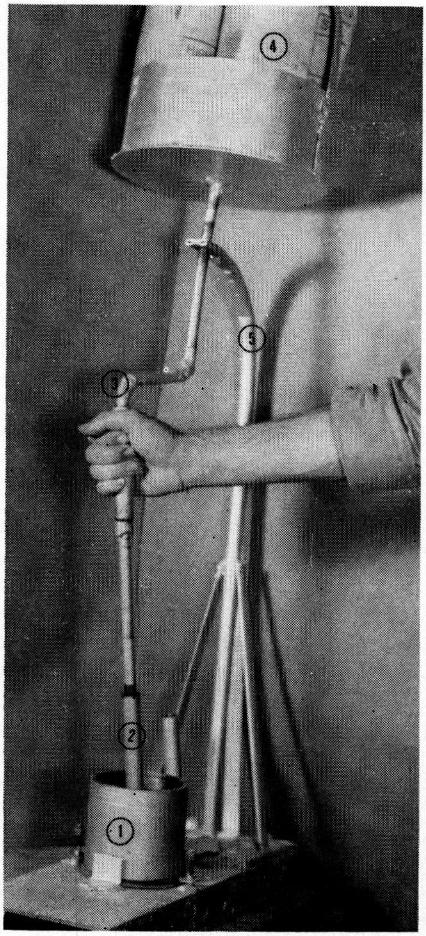

Figure 11.

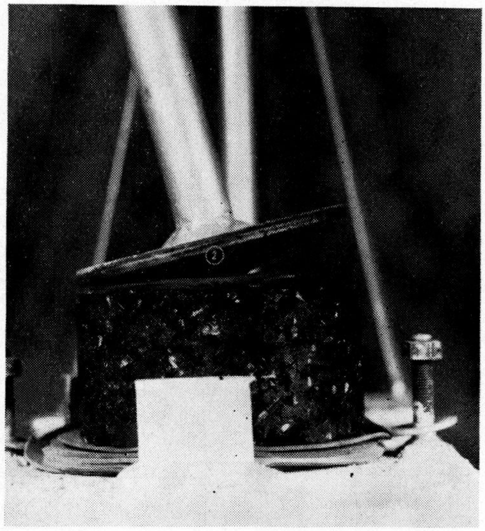

Figure 11(a).

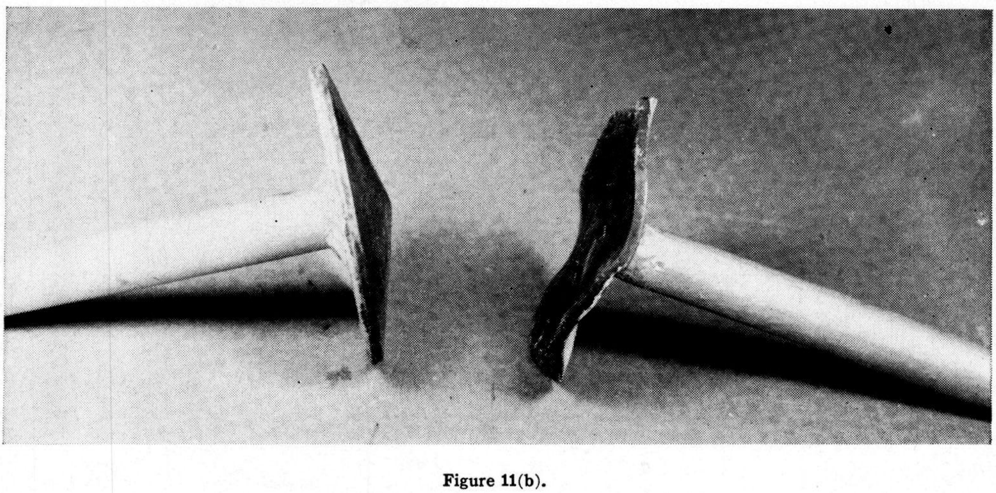

Figure 11(b).

TABLE 8
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 6

Speci-men No.	Molding Method					Specific Gravity	Compact. (by Sp. G.)	Height of Sample	Compact. (by Vol.)	Surface Voids	Degra-dation Factor
	Molding Tempera.	Pres. on Specimen		Revolutions of Foot	Rpm. of Foot						
	F.	lb.	psi.				percent	in.	percent	percent	percent
27	85	100	Variable	200 (coni)	60	1.998	83.62	2.27	79.09	4.53	—
29	85	100	Variable	800 (coni)	60	2.088	87.39	2.17	82.73	4.66	—
31	85	100	Variable	300 (crimp)	60	2.116	88.54	Varied	—	—	—
35	85	100	Variable	300 (coni) 300 (crimp)	60	2.164	90.55	Varied	—	—	—

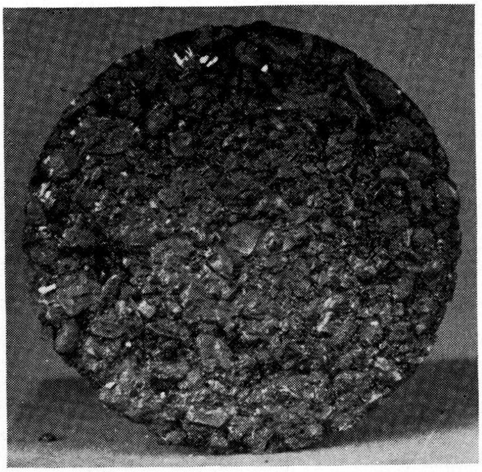

Figure 12.

by measurement, *surface voids*, and *degradation values* were omitted.

Because of the above results, Machine 7 was not subjected to further investigation.

Illustration 14 shows the top surface of Specimen 18 (see Table 9). Note the lower density of the center portion of the specimen.

Machine 8 (Horizontal Shear in a Rectangular Mold)

Description and Operation—Figure 15 shows Machine 8 assembled for operation. Briefly the operator compacts a specimen by applying a compressive load through the hydraulic jack (7) into the specimen contained between two movable compression feet and two movable walls located under the cover plate (5).

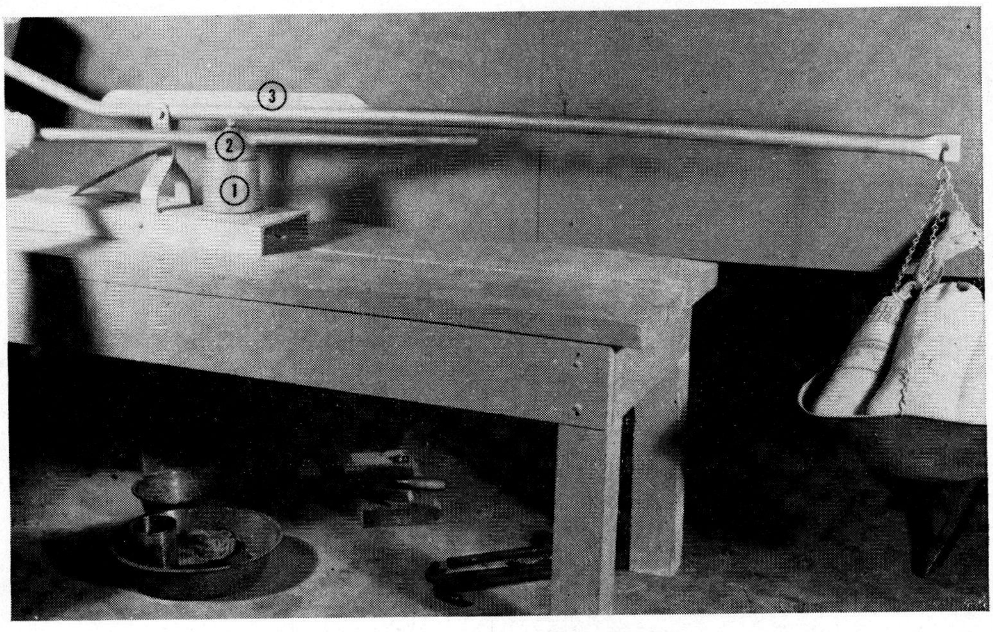

Figure 13.

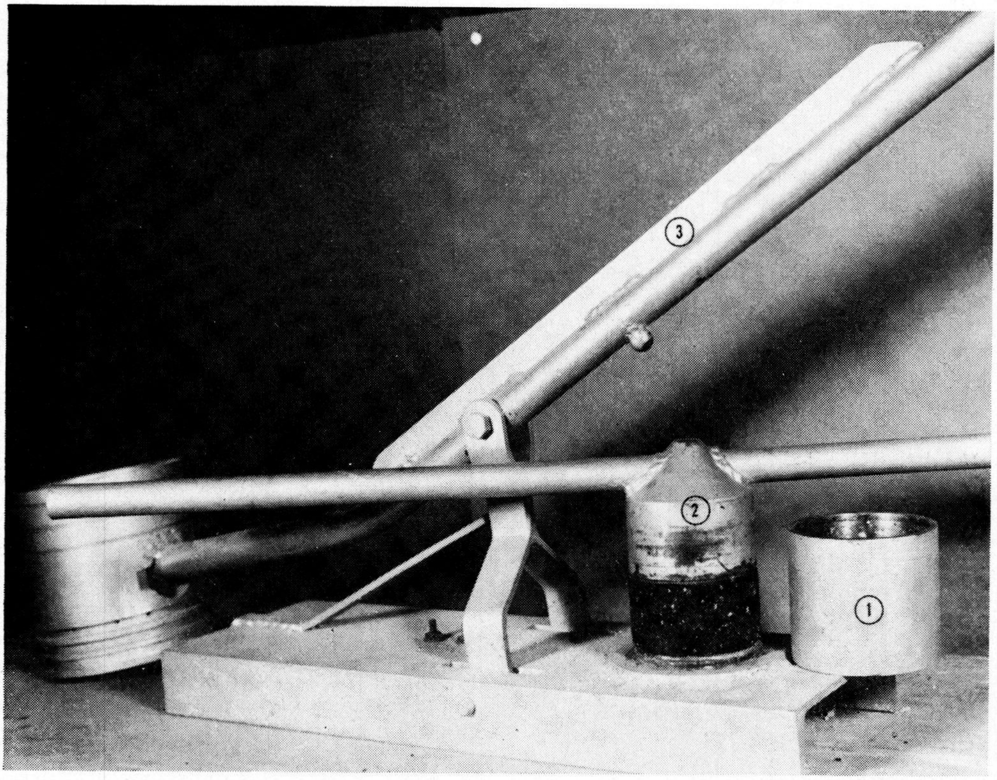

Figure 13(a).

The compressive load is measured on the pressure gage (8).

At a definite initial load (lower than the final load) the specimen is first sheared by operating the handle (10) near the right end of the table prior to the application of the full load. The shearing action facilitates compaction of the specimen with minimum degradation by proper orientation of the aggregate particles under a low initial load.

Illustration 15(b) shows the arrangement of the essential parts of the machine. The compression feet (1) for the beam-shaped mold consist of two machined steel plates, each 8-by 2- by 1-in., bevelled at the ends and welded to the $1\frac{1}{2}$-in.-diameter iron pipes (2) and (3). (An alternate type of mold, square-shaped, as in Figure 15(c), employs two machined steel plates, each 4- by 2- by 1-in.) The plates of the beam shaped mold are braced to the pipes by means of welded iron fins. Pipe (2) is attached by means of a ball joint to the steel alignment bar (6) through which the load from

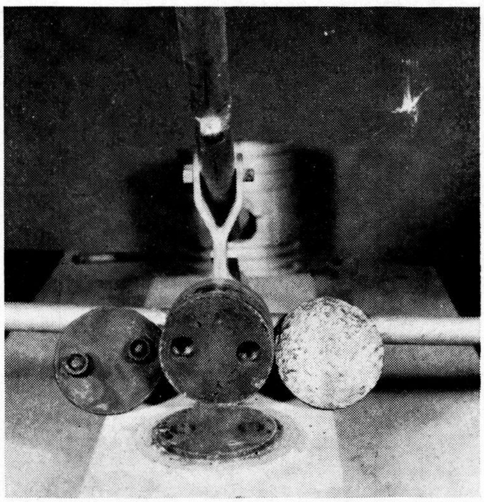

Figure 13(b).

the jack is received. Pipe (3) reacts against a steel alignment bar (not shown in the illus-

tration) through a ball joint. The steel bar reacts through a knife-edge against the top of a J-shaped lever arm, which in turn reacts against a knife-edge at the bottom of the J. Welded to the lower end of the J-shaped lever is the lever arm (9) shown in Figure 15.

the aggregate particles by maintaining the jack load F so that FM = fm. As the Specimen S decreases in thickness (increases in compaction), the jack plunger is extended to offset the decrease. After optimum particle orientation at the desired initial load has been

TABLE 9
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 7

Specimen No.	Molding Method			Specific Gravity	Compact. (by Sp. G.)	Height of Sample	Compact. (by Vol.)	Surface Voids	Degradation Factor
	Molding Temperature	Pressure on Specimen	Oscilla. of Foot						
	F.	*psi.*			*percent*	*in.*	*percent*	*percent*	*percent*
28	85	20	100	2.132	89.22	2.04	87.37	1.85	—
		80	75						
16	95	80	75	2.189	91.63	2.01	—	—	—
33	85	40	300	2.194	91.80	1.99	89.55	2.25	—
32	85	80	150	2.199	92.04	1.99	89.55	2.49	—
45	110	80	80	2.208	92.39	—	—	—	—
23	90	80	100	2.213	92.61	1.98	—	—	15.86
30	85	20	100	2.226	93.15	1.97	90.46	2.69	—
		80	150						
18	90	80	100	2.226	93.17	—	—	—	—
38	90	80	150	2.256	94.40	1.93	92.57	1.83	—
13	92	80	100	2.262	94.66	1.92	—	—	13.73
42	85	80	600	2.283	95.55	1.91	93.30	2.25	19.01
24	90	80	100	2.217	92.76	1.98	—	—	—

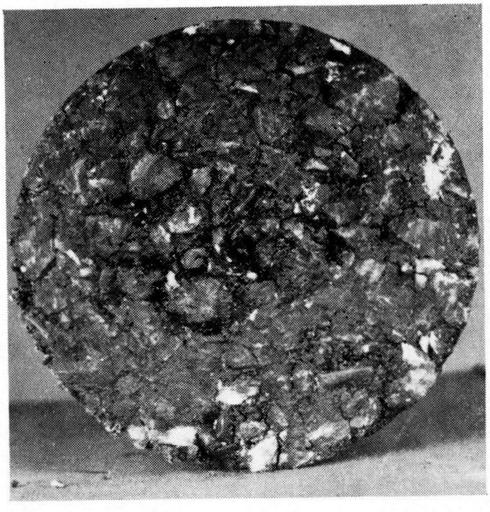

Figure 14.

The equipment described above is mounted on an iron-frame table (11).

At the beginning of the molding operation (see Fig 15(a)), weights are suspended from the lever arm (9) to provide the desired low initial load at which the specimen is manipulated for aggregate orientation. The moment is balanced at all times during orientation of

accomplished (as evidenced by no further decrease in specimen thickness), the final compressive load is applied to the specimen by the addition of weights to lever arm (9), and by increasing the jack load F, again FM = fm.

When a final compressive load was required which exceeded the space capacity of the weight-hook, a steel block was placed behind the top of the J-lever to dispense with the moment. The final compressive load was then applied by the jack only, the magnitude being read on the pressure gage (8).

The shearing action is imparted to the specimen in the following manner: After bolting down the cover (5), the carriage (4), Figure 15(b), pivoted on two upright bolts is oscillated by means of the handle and gear (10), while the rods (2) and (3) being mounted on ball joints remain essentially in a straight line. During oscillation of the carriage, the compression feet slide along the carriage walls, and remain at all times parallel. (See Illustration 15(d) showing the 4- by 2- by 1-in. faces.) Carriage and cover plates are of steel.

This arrangement induces a shearing action throughout the entire specimen whose opposite sides are at all times parallel. The under surface of the carriage cover plate and the base plate of the carriage are case-hardened. This treatment was necessary in order to

reduce the excessive resistance to specimen movement caused by the scarifying action of the aggregate particles on the original metal.

In Figures 15(c) and 15(d) are shown polished steel side-pieces inserted between the carriage walls and the specimen. These are used in molding only the square-shaped specimens.

machine occasioned less aggregate degradation than the laboratory asphalt press in molding to a comparable specimen density (*cf.*, Table 10 with Table 4) for equal specimen-density degradation caused by Machine 8 was comparable to that occasioned by Machine 9. The latter machine was selected as the best molding machine, and it will be described next

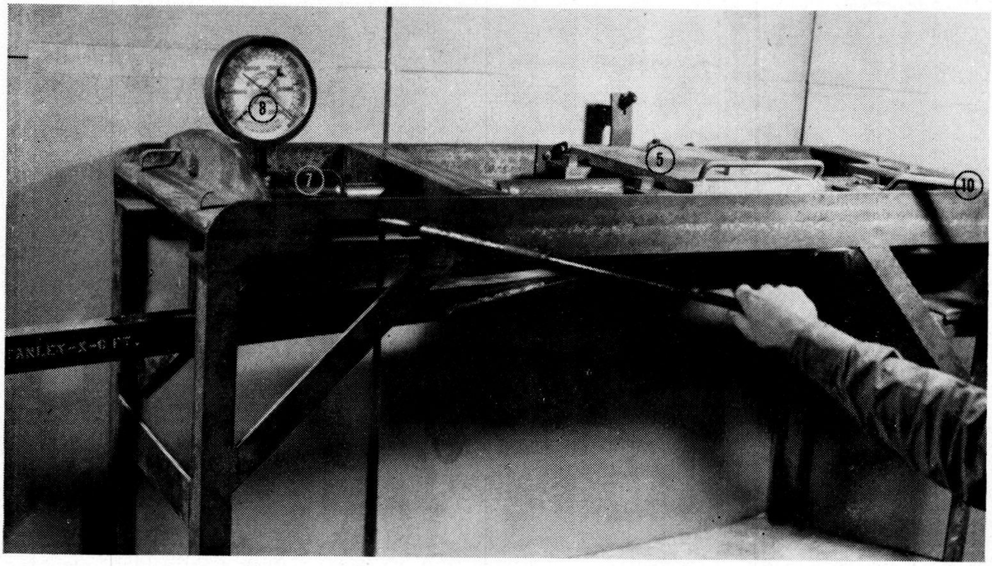

Figure 15.

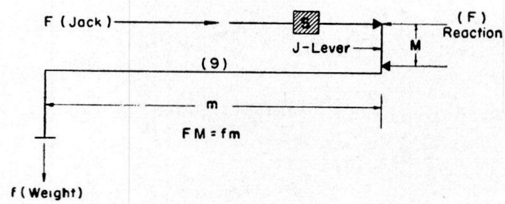

Figure 15(a).

Procedure—Specimens were molded with both types of compression molds, *i.e.*, the ones producing the square and the beam-shaped specimens, at various compressive loads and with various amounts of shearing action.

Discussion—Table 10 shows specimens molded on Machine 8 arranged in order of increasing density. All specimens except 61 were square-shaped, *i.e.*, approximately 4 by 4 by 2 in. Specimen 61 was beam-shaped, approximately 8 by 2 by 2 in. Note that this

In molding square or beam-shaped specimens it was found that the edges of the specimens were not as well compacted as the center portions. This was particularly true of the beam shapes. A cylindrical-shape can be molded to a uniform density much more easily than some other shape (square, beam, cubical, etc.) having a greater length of edges. For some evaluating tests, however, such as bending tests and certain shear tests, a beam-shaped specimen would be required.

Figures 15(c) and 15(d) show a square-shaped specimen being molded.

The test results obtained for Machines 6, 7, and 8 show the evaluation of the basic principle of a desirable machine for molding asphaltic concrete specimens, *viz.*, proper orientation of the aggregate particles at a low load before application of the full compressive load to minimize degradation of the aggregate.

This principle was successfully applied in Machine 9 chosen for molding specimens in the Asphaltic Concrete Research investigations. This machine is described next.

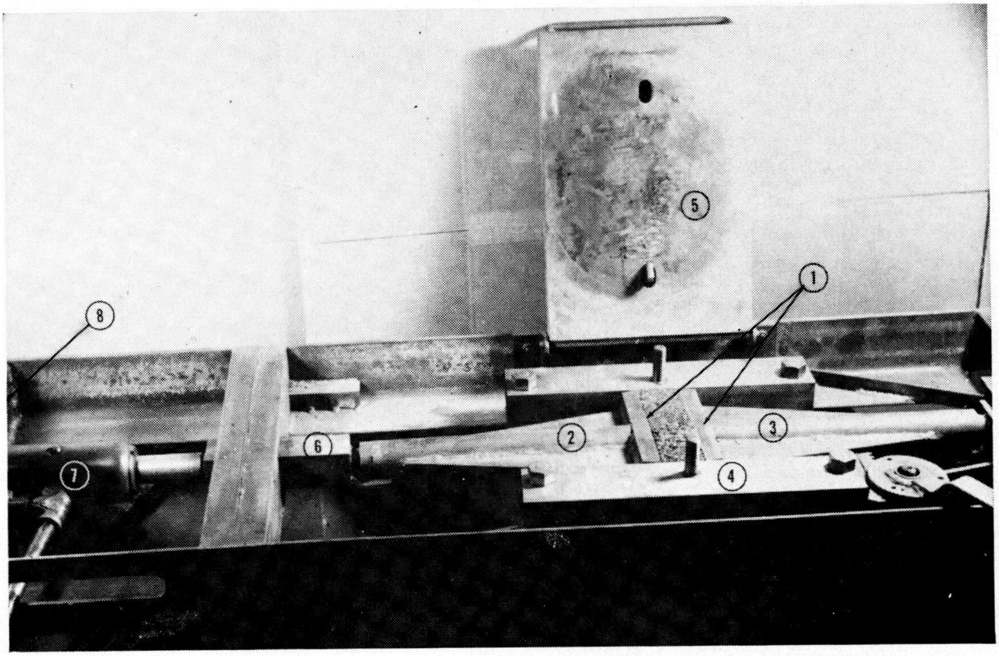

Figure 15(b).

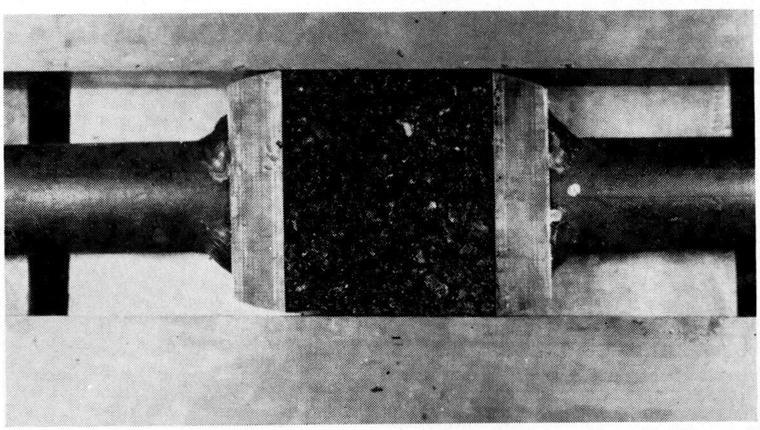

Figure 15(c).

Machine 9 (*Gyratory Shear*)

Description and Operation—It was apparent from the foregoing results obtained on Machines 6, 7, and 8 that aggregate degradation could be more effectively diminished by proper aggregate orientation as the compressive load was increased or, better still, by proper aggregate orientation at a low initial load before application of the full compressive load (as with Machine 8).

As it was felt that an improvement could still be made on the previously designed

machines and as it was economically desirable to continue to use in some form the laboratory asphalt press then employed by the field laboratories, the molding ram, molding cylinder, and molding procedure of that machine were modified on the basis of the aggregate-orientation principle.

Provision was made to impart a gyratory motion to the molding cylinder, either as the compressive load was increased or at a low initial before application of the full compressive load. Figure 16 shows the assembly of the modified ram and mold. During the molding operation one man can actuate the hydraulic jack handle of the laboratory press while another man gives the molding cylinder one revolution per jack stroke. The gyratory motion of the cylinder is continued until further movement of the cylinder is impossible. By this "two-man" molding method aggregate orientation occurs as the compressive load is increased.

Aggregate orientation at a low initial load before application of the full compressive load is effected by a one-man method in which one man gyrates the molding cylinder at 100 psi., gage, until further movement of the cylinder is impossible, whereupon he applies the full load to the specimen.

The assembly (see Fig. 16) consists of a 4-in. ram (1), a molding cylinder, 4.01 in. in diameter and 4 in. in height and equipped with a collar and handles (2), a 4-in. tapered base plate, ½ in. thick (3), and a guide ring (4).

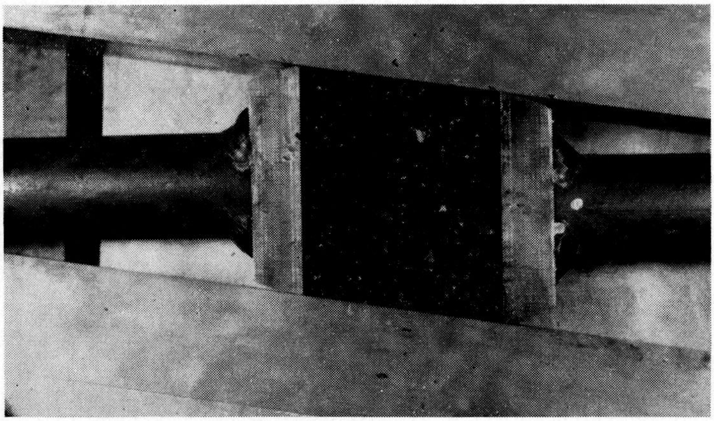

Figure 15(d).

TABLE 10
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 8

Specimen No.	Molding Method		Specific Gravity	Compact. (by Sp. G.)	Height of Sample	Compaction (by Vol.)	Surface Voids	Degradation Factor
	Molding Temperature	Pressure on Specimen						
	F.	*psi.*		*percent*	*in.*	*percent*	*percent*	*percent*
58	90	575	2.135	89.37	2.03	86.41	2.96	23.72
57	90	575	2.152	90.08	2.03	86.30	3.78	23.33
59	90	575	2.191	91.69	2.03	88.55	3.14	19.05
61	90	840	2.252	94.26	1.96	91.43	2.83	23.37
85	85	1792	2.317	96.97	2.03	95.01	1.96	—

The ram is 3¼ in. in diameter with a ⅜-in. flange at the molding end, Figure 16(a). It was made by turning one of the asphalt press's flat rams on a lathe.

The molding cylinder is the same type of cylinder used in the laboratory press. A 1½-in. steel strap, ¼ in. thick is bolted around the cylinder. Welded onto the strap are two ½-in. pipe handles, 5 in. long and spaced 75 deg. apart. A piece of ¾-in. galvanized pipe, 24 in. long (and reamed to fit), is slipped over each of the pipes to provide the handles. Either of

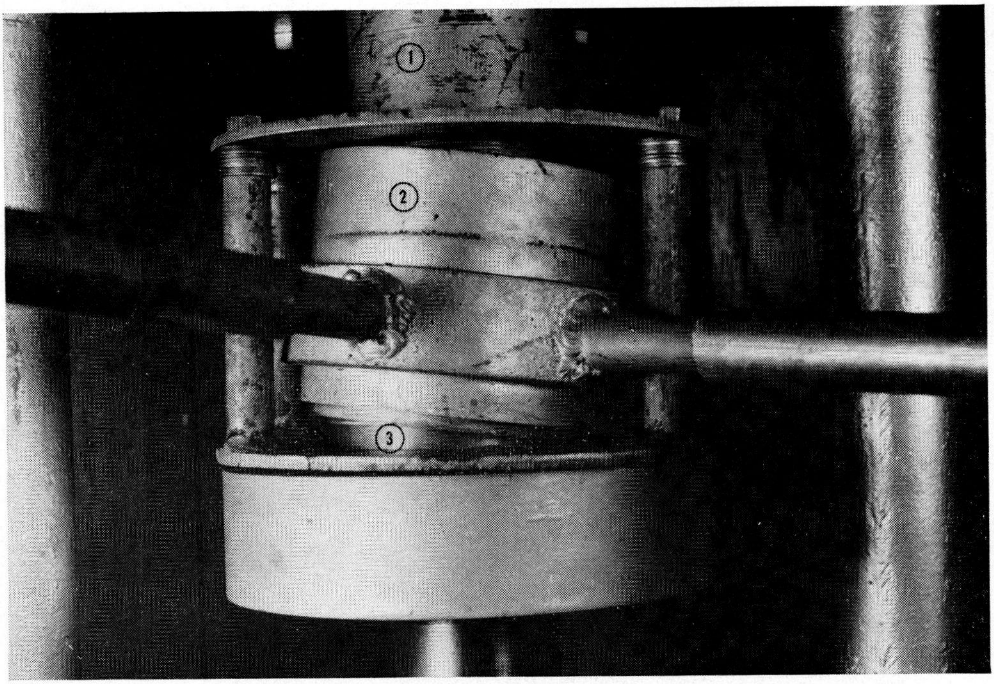

Figure 16.

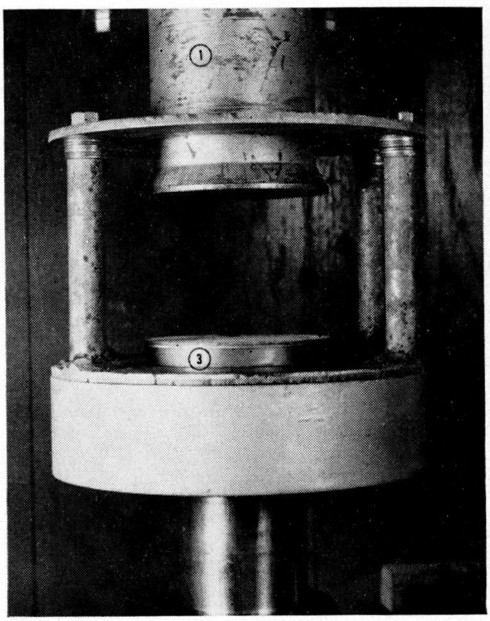

Figure 16(a).

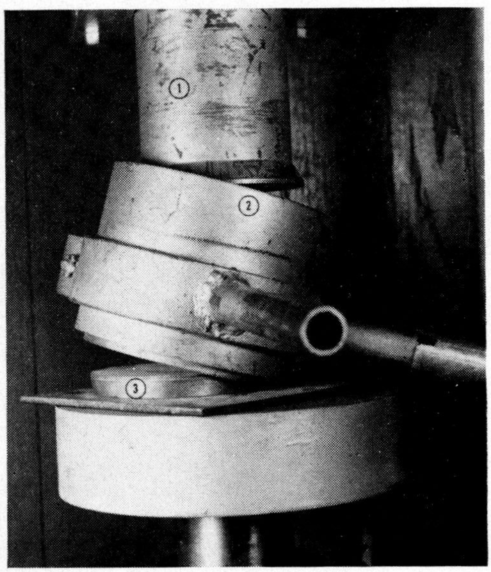

Figure 16(b).

the pipe handles can be used as the jack handle, and notching one of the pipes at one end provides a convenient means of loosening or tightening the release-valve on the jack, as in Figure 16(b). In this picture the guide ring has been removed. The square plate under the base is not part of the assembly.

The base plate tapers from a 4-in. diameter at the top of a 3.8-in. diameter at the bottom (15-deg. taper). Figure 16(b) shows the taper. At all times during movement of the cylinder the base plate remains parallel to the molding face of the ram. Therefore, the top and bottom of the specimen are at all times parallel.

Figures 16 and 16(a) show the guide ring. It consists of two 8-in. circular discs of ¼-in. steel plate spaced 4½ in. apart by four pieces of ½-in. pipe welded to the bottom disc. The top disc has a $4\frac{1}{16}$-in. circular hole for receiving the 1-in. bolts which fasten the top disc. To make the height of the top disc adjustable, washers were placed between the uprights and the disc. Several heights were tried before that of 4½ in. was finally adopted. This spacing gave a clearance of ½ in. above the molding cylinder.

As the operator imparts a gyratory motion to the molding cylinder, any point on the base plate describes a circle with respect to the bottom disc. The base plate is lubricated for easy movement by placing a small amount of oil between it and the bottom disc of the guide ring.

The molding assembly described in the foregoing paragraphs is an experimental model used in the laboratory to correlate compaction and degradation data with that obtained by the other molding machines.

Procedure—For this part of the investigation (comparison of molding machine) emphasis was not placed on the one- and two-man methods of molding with Machine 9, as the development of the best molding method was reserved for the latter part of the investigation. It was desirable here to evaluate only the design of Machine 9. Both molding methods, however, were used employing the same final load on the specimen (1,592 psi. as determined from preliminary tests). Another specimen was molded by the one-man method at 3,125 psi., the same pressure employed by the field in molding cold mixes.

Discussion—Table 11 shows averaged test results for three specimens molded on Machine 9 according to the two-man method at 1,592 psi. on the specimen. Two specimens were molded at the above pressure, and one specimen was molded at 4,909 psi., gage (3,125 psi. on the specimen), according to the one-man method at 4,909 psi., gage, Machine 9 gave a degradation factor of 33.91 percent, considerably less than that obtained with the laboratory asphalt press (44.97 percent) in molding to about the same density with the same load according to the method employed in the field (*cf.* specimen 68 in Table 11 with the averaged results of specimens 36 and 39 in Table 4). A density of 96.54 percent was obtained with the former machine and 96.66 percent with the latter.

An average degradation value of about 23 percent was occasioned by Machine 9 in molding to about 94 percent compaction at 2,500 psi., gage (1,592 psi. on the specimen). This compressive load was the minimum load that consistently gave the desired 94 percent compaction. Degradation occasioned by this load should be compared with that obtained with

TABLE 11
CHARACTERISTICS OF DESIGN A SPECIMENS MOLDED ON MACHINE 9

Specimen No.	Molding Method				Specific Gravity	Compaction (by Sp. G.)	Height of Sample	Compaction (by Vol.)	Surface Voids	Degradation Factor
	Molding Temp.	Gage	Pres. on specimen	Oscillations of the Mold						
	F.	*psi.*	*psi.*			*percent*	*in.*	*percent*	*percent*	*percent*
72	90	2500	1592	1/jack Stroke	2 213	92.63	2.02	89.54	3.09	23.37
74	90	2500	1592	25	2.252	94.25	1.96	92.29	1.96	27.93
75	90	2500	1592	1/jack Stroke	2.363	93.59	1.98	91.36	1.23	22.47
69	90	2500	1592	21	2 234	93.48	1.97	91.59	1.89	22 06
76	90	2500	1592	27	2.244	93 91	1.98	91 36	2 55	22.53
68	90	4909	3125	27	2.307	96.54	1.91	94.47	2 07	33 91

the laboratory asphalt press in molding to 4,909 gage psi. in order that the advantages of Machine 9 might be indicated. On this basis of comparison, 11.06 percent (44.97 percent minus 33.91 percent) less degradation was caused by Machine 9.

It was observed that about 93 percent of the final specimen density was obtained by the gyratory motion of the mold (one-man method) without any application of the compressive load other than the 100 gage psi. used to confine the mix vertically during the gyration. This fact well illustrates the effectiveness of proper particle orientation at a low initial load before application of the full compressive load.

TABLE 12
DESIGN C

Screen Size	Cumulative Weight in Grams	Percent	
		Individual	Cumulative
½-in.-⅜-in.	133 2	16.0	16.0
⅜-in.-¼-in.	283 1	18 0	34 0
¼-in.-10	566.2	34 0	68 0
10-20	609 5	5.2	73 2
20-30	647 0	4.5	77.7
30-40	680 3	4 0	81 7
40-50	704 5	2 9	84 6
50-60	716 1	1 4	86 0
60-80	730 3	1 7	87.7
80-100	738.6	1 0	88 7
100-200	760 3	2.6	91.3
-200	852 7	8 7	100.0
Total		100 0	
RC-2	908.1 (6 1 per cent of weight of total mix)		
Less volatiles	11.3		
Final weight	896.8		

In view of the foregoing results, Machine 9 was selected as the one meeting the requirements previously outlined.

DEVELOPMENT OF PROCEDURE FOR THE SELECTED MACHINE

After selecting Machine 9 as the most practical one for producing the desired specimen density (94 percent) with the minimum amount of degradation, it was necessary to develop the best method of applying the shearing action to the mix prior to applying the final load tentatively decided upon (1,592 psi.). With the final pressure constant the following variables required investigation: the amount of gyratory motion given to the mold (or amount of shearing action applied to the mix) and the method of imparting that motion. Several molding procedures involving changes of the above factors were tried in order to determine the one to be adopted. Degradation and compaction results obtained by that procedure were then to be compared with results obtained with the laboratory asphalt press.

The above work called for the most accurate control of aggregate grading and mix proportions:

Mix Design and Control

The mix design used in this part of the investigation, and called Design C was essentially the same as Design A. More careful control, however, was employed to insure a constant aggregate grading and thus make all degradation comparisons valid. Absolute control of the aggregate grading was secured by blending and storing all sizes separately from ½ to ⅜ in. to minus the 200 mesh (as in Table 12). Aggregate grading and proportions of the mix are shown in Table 12.

Mixes of Design C were prepared and cured in the same manner as previously described for Design A.

Procedure

The amount of shearing action applied to the mix depended upon the number of gyratory rotations of the mold and the amplitude of the gyratory rotations.Two methods of applying the shearing action (which will be described in detail later) were tried. One method (the one-man type) consisted of one man rotating the mold as long as the mix was workable at 50 psi., gage, and then of his applying the full load of 1,592 psi. on the specimen. The two-man method consisted of one man rotating the mold while another man applied one stroke of the hydraulic jack per mold rotation. Rotation of the mold was continued until further rotation was impossible, whereupon the remainder of the compressive load was applied.

As the *number* of mold rotations necessary for a given mix design was intrinsically variable in either method (depending upon operators), that variable was ignored. (Actually, in comparing operators or methods the number of mold rotations varied only slightly.) When different types of mix designs are molded, each type is considered as having received the same treatment, regardless of the number of

mold revolutions, because each type is gyrated until further movement of the mold is impossible. In other words, each type is gyrated to the same degree of shearing resistance before application of the compressive load.

The other variable in the amount of shearing action applied was the amplitude of the gyratory motion, which depends upon the spacing between the top of the molding cylinder and the top plate of the guide ring. Both methods of applying the shearing action were therefore compared at the following guide-ring spacings: ⅛, ¼, and ½ in.

The one-man method is described as follows: Mold filled with mix and guide ring (set at one of the spacings) are placed on the platen of the press. The platen is raised, so that the ram comes in contact with the specimen and exerts a pressure of 50 psi., gage. A gyratory motion consisting of three revolutions is then given to the mold by means of the handles. This operation constitutes a cycle. After shearing the specimen thus, the gage pressure drops to zero. The operator then reapplies the above pressure of 50 psi. again rotates the mold three times. This procedure is repeated until it is impossible to move the mold. Usually about 9 cycles or 27 mold rotations suffices. Thereupon the full compressive load is applied to the specimen.

The two-man method consists of the following procedure: Mold filled with mix and guide ring set at one of the spacings, or lifts, are raised on the platen until the ram comes in contact with the specimen. One operator imparts a continuous gyratory motion to the mold while another operator applies the compressive load to the specimen. One stroke of the jack handle is made for each revolution of the mold. This procedure is continued until further movement of the mold is impossible, whereupon the full compressive load is applied to the specimen.

Two specimens were molded according to each method and at each guide ring spacing. A pressure of 1,592 psi. on the specimen was employed throughout the test.

TABLE 13
DEVELOPMENT OF MOLDING PROCEDURE FOR MACHINE 9 EMPLOYING DESIGN C SPECIMENS

Specimen Numbers[a]	Molding Method					Density (Water Displ.)	Degradation Factor
	Molding Temp.	Procedure	Gage	On specimen	Lift[b]		
	F.	*type*	*psi.*	*psi.*	*in.*	*percent*	*percent*
7-33	90	One-man	2500	1592	⅛	91.39	28.79
6-8	90	Two-man	2500	1592	⅛	91.75	28.43
5-9	90	One-man	2500	1592	¼	92.76	26.13
4-10	90	Two-man	2500	1592	¼	92.91	25.48
11-32	90	One-man	2500	1592	½	94.91	25.66
12-30-31	90	Two-man	2500	1592	½	93.38	27.25

[a] An average value.
[b] Spacing of the guide ring above the molding cylinder.

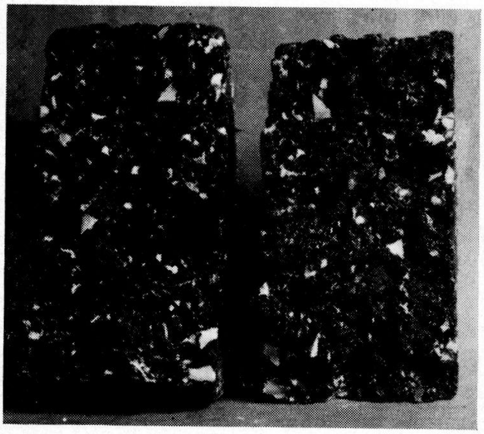

Figure 17.

Discussion

Table 13 shows the average of duplicate specimens molded on Machine 9 at lifts of ⅛, ¼, and ½ in., according to the one-man and two-man procedures. Since there was only a fraction of 1 percent difference in results obtained by the one-man and the two-man procedures at any lift, the former procedure was, of course, adopted. Specimen density increased with the height of the lift, or guide-ring, spacing above the molding cylinder, that is to say, with the amount of shearing action to which the specimen was subjected before application of the full compressive load.

A density of 94 percent was consistently obtainable with the ½-in. lift.

The molding procedure evolved then for future use was the one-man method employing a ½-in. lift for the gyratory motion at 50 psi. gage, and a final compressive load of 2,500 gage psi. (1,500 psi. on the specimen).

Figure 17 shows a specimen molded on Machine 9 according to the adopted molding procedure. The specimen was warmed and carefully broken into halves to show aggregate degradation occasioned by molding. A minimum of the aggregate was broken in separating the halves.

TABLE 14

DENSITY AND DEGRADATION FOR DESIGN C SPECIMENS MOLDED ON MACHINE 1

Specimen Numbers[a]	Molding Method				Density (Water Displ.)	Degradation Factor
	Molding Temp.	Gage	On specimen	Ram		
	F.	*psi.*	*psi.*	*type*	*percent*	*percent*
13–16	90	4909	3125	Flat	95.50	37.58
20–21	325	4909	3125	Flat	93.66	39.04
14–17	90	4909	3125	Both Rams	97 26	45.94
39–40	90	4909	2546	Both Rams	96.83	45 45
37–38	90	4909	1910	Both Rams	95.28	40.13
35–36	90	4909	1273	Both Rams	93.44	35.43
15–18	325	4909	3125	Both Rams	96 94	47.37

[a] An average value.

COMPARISON OF THE MACHINE 9 WITH THE LABORATORY ASPHALT PRESS

After selecting the best molding method to be employed with Machine 9, it was desirable to compare the density and degradation results obtained by that method with results obtained by the laboratory asphalt press. It was desirable not only to make the comparison with the L.P.A. operated according to the molding method used in the field (letting the density and degradation be whatever they may) but also to make the comparison with the press operated to give a density of about 94 percent, *i.e.*, a density comparable to that obtained with the Machine-9 procedure).

Procedure

Specimens of Design-C mix were molded in duplicate on the laboratory asphalt press employing both rams (flat and corrugated) at 3,125 psi. on the specimen and two molding temperatures (325 F. and 90 F.). Both rams were also employed in molding duplicate specimens at 90 F. under the following pressures: 1,273; 1,910; and 2,546 psi. The flat ram alone was employed in molding duplicate specimens at 90 and at 325 F. under 3,125 psi.

Discussion

Table 14 shows density and degradation values for specimens (13–16 and 20–21) molded on the laboratory press at 90 F. and 325 F. with the flat ram and the pressure employed in 1939 by the Texas Highway Department. Other specimens at 90 F. molded with both rams and at different pressures to determine one producing about 94 percent density are also shown (see averages of Specimens 14 to 17, 39 to 40, 37 to 38 and 35 to 36). The average results for Specimens 15 and 18 were obtained at the pressure and temperature employed at the above mentioned date.

Average density and degradation results obtained for Specimens 11 and 32 (see Table 13) molded on Machine 9 according to the adopted method will now be compared with the results shown in Table 14 for the laboratory asphalt press. Machine 9 occasioned 25.66 percent degradation at a density of 94.91 percent. Employing a pressure of 3,125 psi. (on the specimen) and the flat ram with the laboratory asphalt press a density of 95.50 percent and degradation of 37.58 percent were obtained at 90 F. and 93.66 percent and 39.04 percent, respectively, at 325 F. While these densities are comparable with that obtained on Machine 9, the degradation factors exceed that for Machine 9 by about 13 per cent.

Molding with the laboratory asphalt press at a pressure producing about 94 percent density occasioned 35.43 percent degradation

(average for Specimens 35 and 36 in Table 14) or about 10 percent more degradation than was caused by Machine 9.

Specimens molded on the L.P.A. according to the method used in the field for cold mixes showed 96.94 percent density and 47.37 percent degradation, or 21.71 percent increase in degradation (47.37 to 25.66) for a 2.03 percent increase in density (96.94 to 94.91). See the averages per Specimens 15 and 18 in Table 14. Note also in Table 14 the increase in degradation caused by increasing the pressure on the specimen from 1,273 to 3,125 psi.

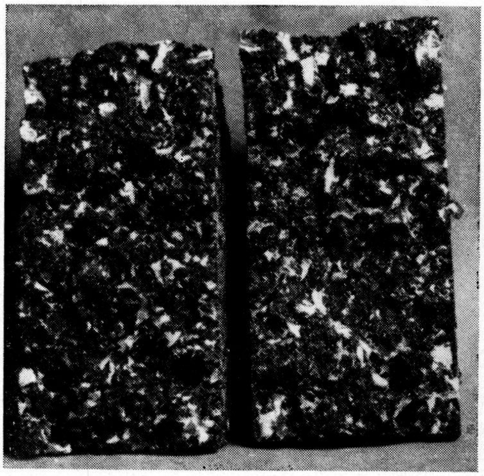

Figure 18.

That the laboratory asphalt press occasioned a greater amount of degradation than did Machine 9 in molding to a comparable density is graphically shown by the specimens in Figures 17, 18, and 19. To insure that only the degradation caused by molding be represented each specimen was warmed and gently broken into halves.

Figure 18 represents the degradation occasioned by the laboratory asphalt press and flat ram operated at the pressure and specimen temperature (4,909 gage psi., or 3,125 psi. on the specimen, and 325 F.) employed in the field. The treatment corresponds to that given Specimens 20 and 21 in Table 13.

Figure 19 represents the degradation in a specimen occasioned by the laboratory asphalt press operated according to the field procedure for cold mixes, *i.e.*, corrugated and flat rams at 4,909 psi., gage, (3,125 psi. on the specimen) and specimen temperature of 325 F. The above treatment corresponds to that given Specimens 15 and 18 in Table 14.

Note in the photographs, and also in Table 14, that the use of both rams (corrugated and flat) produces more density and consequently more degradation than the flat ram. Machine 9 produces visibly less degradation than either of the foregoing methods at a slightly lower density.

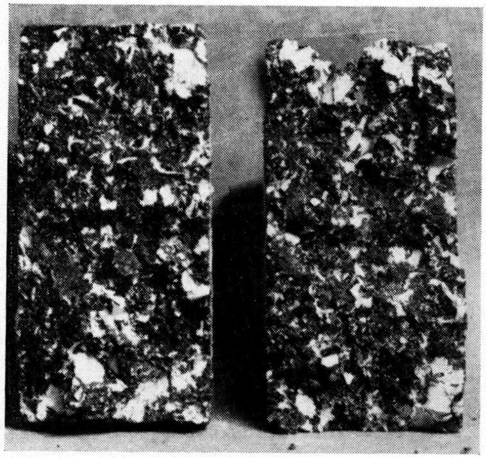

Figure 19.

DISCUSSION

After experimenting with nine types of molding machines involving molding by direct compression at various pressures (laboratory asphalt press and Southwark-Emery Hydraulic Compression Machine), impact (Proctor Soil Compaction Machine), vibration (B.P.R. Vibratory Machine), rolling, simulating construction practice (Machine 5, pneumatic roller), aggregate orientation by shearing under an increasing unit vertical load (Machine 6), aggregate orientation by shearing under a constant vertical load (Machine 7), and aggregate orientation by shearing at a very low initial load followed by the application of the full compressive load (Machines 8 and 9), it was felt that all the common molding principles were utilized. From the nine machines, Machine 9 was selected as the one

affording the most promise for rigid testing under various conditions and for rigid comparison with the laboratory asphalt press (Machine 1) then in use.

The basis of comparison was the ability of the machine to produce a specimen whose density and degradation characteristics approached as nearly as possible those of satisfactory asphaltic concrete pavement in service from about four months to four years. A density of 94 percent and any degradation value appreciably less than that occasioned by the laboratory asphalt press and as near as possible to that found in asphaltic concrete pavement containing the same stone were considered satisfactory.

The data indicate that Machine 9 is to be preferred to the laboratory asphalt press (Machine 1) in use in 1939 for producing a laboratory specimen whose characteristics simulate those of asphaltic concrete pavement in service.

It should be remembered that only part of the test results accumulated during the investigation are reported here in order to facilitate a comparative study of the different machines by the reader.

ACKNOWLEDGMENTS

Twelve years ago the laboratory work described in this paper was performed in the Materials and Tests Division's laboratory at Camp Hubbard, Texas. The late W. H. Wood was materials and tests engineer. The work was performed under the general direction of Walter C. Youngs, Jr., former laboratory research engineer, now of the Atomic Energy Commission.

Special acknowledgements are due Albert L. Love, Jr., former concrete engineer, now with the U. S. Engineers, under whose excellent direction this work was performed, and to Edwin O. Beatie, former laboratory assistant, now representative of The Texas Company, for his meticulous note recording and transcribing for the original draft of this paper.

Machine 6 (conical mold) and Machine 7 (horizontal shear in a cylinder) were designed by Charles C. Raines, former laboratory assistant, now a partner in the Rainhart Company of Austin, Texas; Machine 8 (horizontal shear in a rectangular mold) was designed by L. S. Snodgrass, former laboratory assistant, retired; Machine 9 (gyratory shear) was designed by O. A. Philippi and Charles C. Raines.

Harry A. Sandberg, Jr., asphalt engineer, is responsible for the adaptation of the gyratory shear machine to molding specimens 4 in. in diameter and 8 in. in height for testing by the triaxial method. This appears in the appendix.

Acknowledgments are due all personnel of the asphaltic concrete section of the laboratory for many valuable suggestions and much hard work.

APPENDIX

STANDARD METHOD FOR MOLDING ASPHALTIC CONCRETE SPECIMENS (TEST 4 FROM TEXAS HIGHWAY DEPARTMENT CONSTRUCTION BULLETIN C-14)

Procedure

1. Throughout this procedure keep the valve on the line leading to the stability recorder closed.

2. Wipe out the molding cylinder with a rag lightly moistened with kerosene. Place several drops of oil on the bottom disk of the guide ring and center the molding cylinder in the guide ring. Insert the base plate with the large diameter up, and place a paper gasket over the base plate.

3. Hot-mix asphaltic-concrete mixtures shall be molded at a temperature of 250 F. ± 5 deg. Cut-back asphaltic concrete mixture shall be cured to a constant weight and shall be molded at a temperature of 100 F. ± 5 deg. Weigh on the torsion balance to the nearest 0.5 gram an amount of the mix sufficient to make a specimen approximately 2 in. in height. If the mix contains aggregate larger than 1 in., remove this aggregate from the sample by rubbing the mix through a 1-in. screen. Small material clinging to the large aggregate pieces should be rubbed off if possible. If a trial mix sufficient in size to produce only one specimen is being used, scrape the material clinging to the mixing trowel and sides of the pain into the bulk of the mix.

4. By means of the bent spoon and special

funnel (see Fig. B) fill the cylinder approximately one-third full and press the mix down lightly with the spoon. Fill the cylinder two thirds full and press the mix down. Place the remainder of the sample in the cylinder and press it down so that the top of the sample is level. Cover the mix with a paper gasket. Be very careful at all times to avoid segregation or loss of material while placing it in the cylinder.

Figure A.

5. Fasten the compression ram firmly in the reaction head of the press and center the molding assembly on the platen of the jack. Close the release valve on the jack.

6. Apply pressure until the gauge registers 50 psi. Attach handles to the molding cylinder and impart a gyratory motion to the cylinder (see Fig. C) until three complete revolutions have been made. The top and bottom of the cylinder shall be in continuous contact with the top and bottom discs of the guide ring during the gyration (See Fig. D). Repeat application of 50 psi., gauge pressure, and gyration until further movement of the molding cylinder is extremely difficult. If the proper degree of compaction has been reached, one full stroke of the jack should cause the dial pointer to move approximately 100 psi. At the conclusion of each gyratory movement, and particularly at the conclusion of the last movement, be sure that the molding cylinder is not tilted, but seats squarely on the lower guide ring.

7. Apply a gauge pressure load of 2,500 psi. (1,588 on specimen) at the approximate rate of one jack stroke per sec. Open the release-valve on the jack, allow the platen to fall, and remove the guide ring and base plate from the assembly. Close the release-valve, fit the molding cylinder over the extraction ring and center the cylinder under the ram. Press the molded specimen out of the mold by raising the platen. Mark the top of the specimen.

8. Measure the height of the specimen (average of four measurements). The specimen shall be $2 \pm \frac{1}{16}$ in. or 2 ± 0.06 in. high. If the height is not within this tolerance, the specimen shall not be used and the weight of sample required to produce a specimen of the proper height shall be calculated according to the following formula:

Figure B.

$$\text{Weight (grams) of sample to be used} = \frac{2.00}{H} \times W$$

Where:

W = weight (grams) of specimen.

H = height (in.) of specimen.

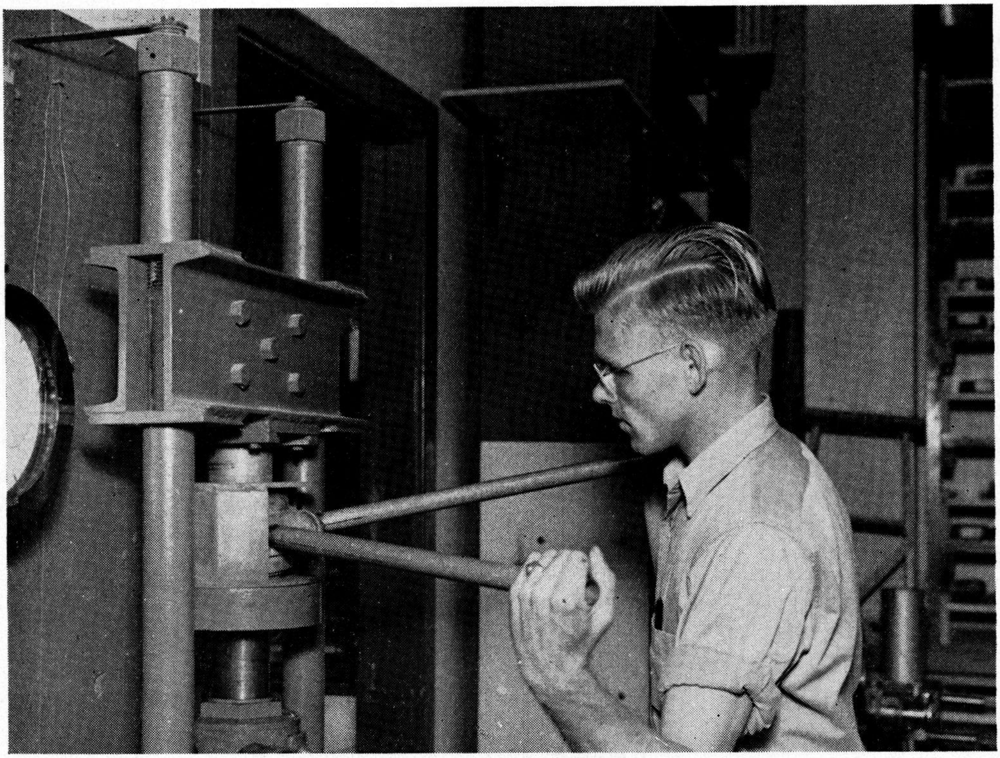

Figure C.

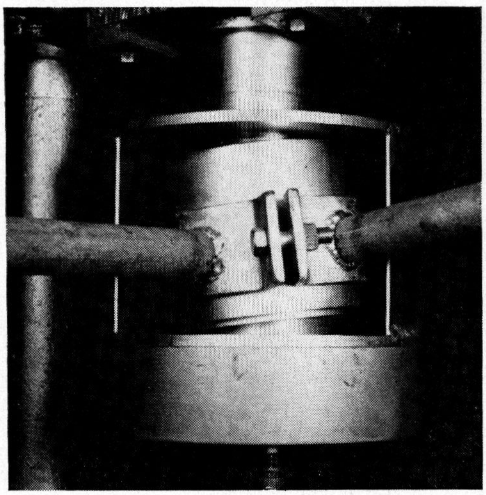

Figure D.

ADAPTING THE GYRATORY MOLDING MACHINE FOR MOLDING SPECIMENS OF HEIGHTS GREATER THAN 2 IN.

A satisfactory method has been developed using the gyratory mold with no major changes required to the machine itself. It is necessary to have larger molds, guide rings, compression rams, and molding handles made up; however, these can be made in any machine shop.

The molding procedure is the same as detailed in *Construction Bulletin C-14*, Test No. 4, with the two modifications listed below:

1. A final gauge pressure of 6,000 lbs. (3810 psi.) is applied to the specimen at the rate of one stroke per second.
2. The pressure is maintained for a period of 60 sec. before release.

In order to determine if the specimen was uniform throughout its length, specimens were molded and cut into sections on the laboratory stone saw. Specific gravity determinations were made on the individual sections. Also, in order to compare these large specimens with standard two inch specimens, several types of mixtures using different aggregates were made up and the densities determined. The correlation data are shown in the tables. It should be noted that all values shown in the tables are average values obtained from three 2-in. and five 8-in. specimens.

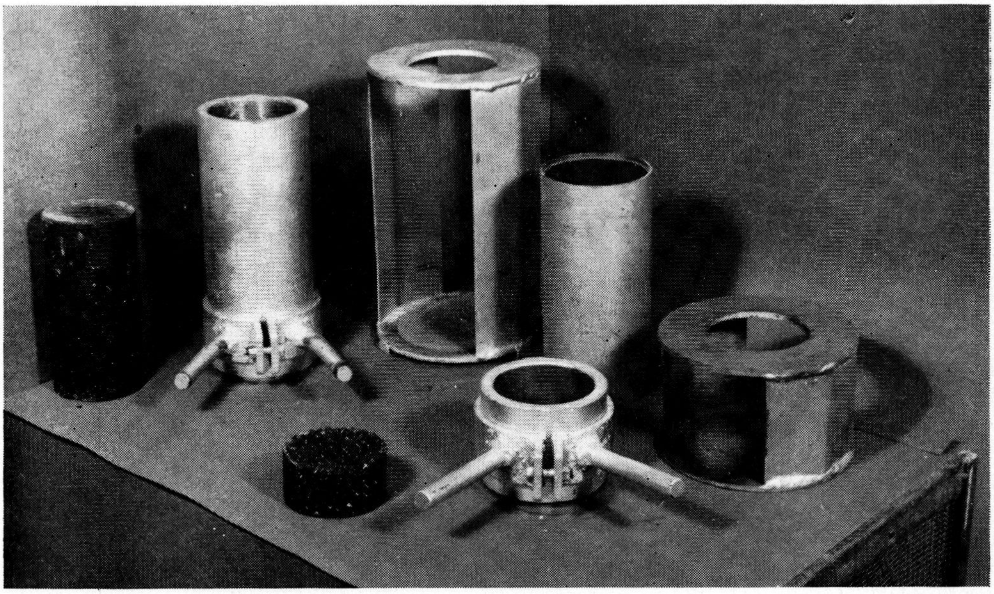

Figure E.

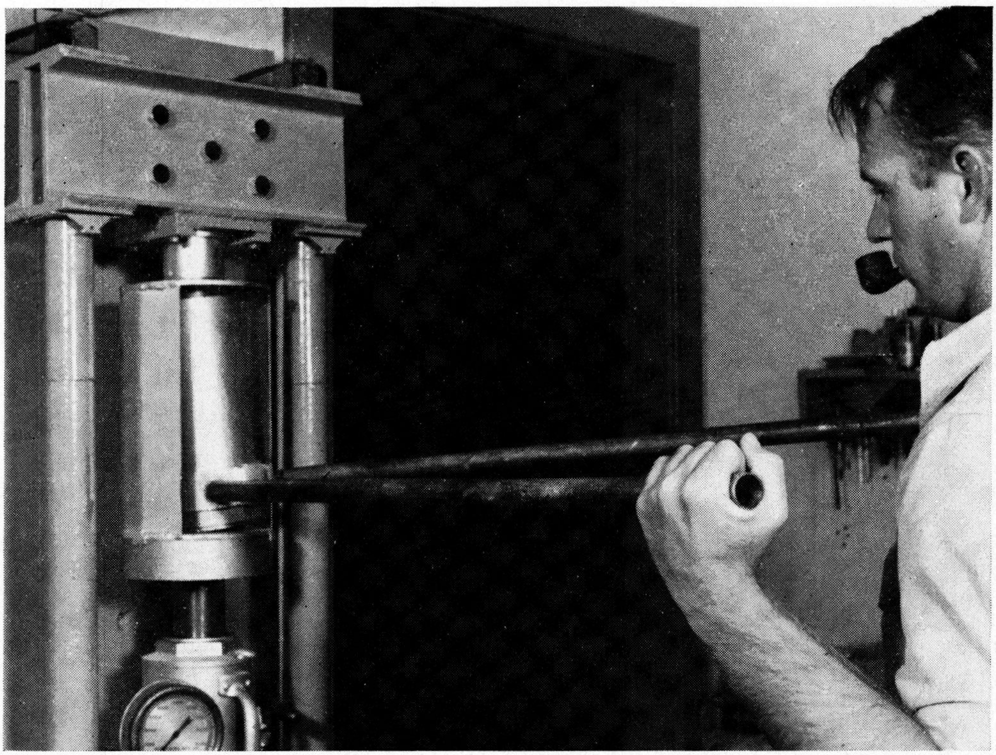

Figure F.

The tolerance on specific gravities determinations on standard 2-in. specimens is plus or minus 0.02. Assuming the same tolerance on large specimens it can be seen from the tables above that on a whole satisfactory test results are obtained using the modified gyratory molding procedure.

TABLE A

	Specific Gravity (C-14, Test 5)		
8-in spec. cut into 3 equal sections	Top $\frac{1}{3}$ 2.24	Middle $\frac{1}{3}$ 2.23	Bottom $\frac{1}{3}$ 2 24
8-in. spec. cut into 2 equal sections	Top $\frac{1}{2}$ 2.22		Bottom $\frac{1}{2}$ 2.21

TABLE B

Material	Specific Gravity (C 14, Test No. 5)	
	8 in. spec.	2-in spec.
Dorsey pit sand	2.10	2.11
Hartley Co. (1st run)	2.20	2.20
(2nd run)	2.21	2.21
Servtex (total mix)	2.26	2.29
Servtex coarse agg. Janes sand	2.21	2.22
Servtex coarse agg. Servtex dust Janes sand	2.25	2.26
Janes gravel Servtex dust	2.32	2.33
Janes gravel Janes sand	2.26	2.29

METHYLCHLOROSILANES AS ANTISTRIPPING AGENTS

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SYNOPSIS

STRIPPING, a major source of failure in bituminous pavements, is caused by the displacement by water of the bituminous film on the surface and the resultant loss of adhesion between the aggregate particles. Although many techniques have been suggested to prevent stripping and subsequent pavement failures, none has met with outstanding success.

Stripping occurs most frequently when sandstone, chert, or any rock classified by geologists as acidic is used as aggregate. Limestone, dolomite, and the basic igneous rocks cause relatively little trouble. Unfortunately, limestone and the basic igneous rocks are not readily available in all localities where bituminous pavements must be constructed.

The siliceous rocks are hydrophilic, that is, water attracting, while limestone and the basic rocks are relatively hydrophobic. If an aggregate which is hydrophilic could be treated to make it hydrophobic, its resistance to stripping when coated with asphalt would be greatly improved.

This paper describes a method for coating a hydrophilic aggregate with a thin, tightly-bound film of silicone resin which will present a hydrophobic surface to the asphalt. The aggregate is exposed in a surface-moist condition to the vapor of a mixture of methylchlorosilanes, which react with the film of moisture on the aggregate to form a coating of silicone resin with a thickness of the order of a few hundred molecules. After exposure to the vapor, the aggregate is strongly hydrophobic.

In the laboratory, seven aggregates were investigated for stripping, with and without the silicone treatment. On the basis of three stripping tests, it was found that the performance of siliceous aggregates can be greatly improved by treatment with methylchlorosilanes.

● STRIPPING ACTION ordinarily begins at the bottom of the pavement and progresses gradually upward, its rate of progress being closely related to the density of the pavement. Therefore, the damage caused by stripping is usually not apparent until after the pavement has failed over a large area.

Stripping is not frequent in the upper portion of the pavement for two reasons: first, because the wearing course is denser than the