U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Public Roads

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ARMY SECTIONAL BRIDGE ERECTED OVER DAVIDSON RIVER, PISGAH NATIONAL FOREST

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U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

PUBLIC ROADS

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TESTS OF IMPACT ON PAVEMENTS BY THE BUREAU OF PUBLIC ROADS

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Second Article.

THE first article of this series was devoted to a description of the methods employed in making the tests of impact on the various pavement slabs, a discussion of the relation between impact force and equivalent static load as measured by the copper cylinders and to the development of a method by which the force of impact, eliminating the effect of the cushion provided by the copper cylinders, can be computed from the space-time curves.

This article reports the behavior of the various pavement slabs in terms of the impact force which they sustained, the forces being computed from the space-time curves by the method previously described.

As described in the preceding article, the slabs were first subjected to 500 blows from an initial height of one-eighth inch, taking a space-time curve of the first five blows and measuring the settlement of the slab after the two hundred and fiftieth. The testing was then continued for 250 more blows without setting the machine for a new height of fall, and space-time curves were again taken for the first five blows, measuring the settlement after the last blow. Beginning with the five hundredth blow the height of fall was increased by three-eighths of an inch and two sets of 250 blows each were delivered at this height making space-time curves and taking elevations for settlement as before. The manner in which the height of fall was increased after each 500 blows has already been described.

The relative behavior of the slabs is expressed concretely by the computed impact force to which each specimen was subjected before and after the first crack developed, but in comparing the slabs it was necessary to consider also the number of blows delivered, the height of fall, the rate of settlement of the center of the slab, the character of the failure and the moisture content and supporting value of the subgrade.

FIRST CRACK THE CRITERION OF FAILURE.

Failure was considered to have occurred with the first crack, but in some cases it was difficult to determine the exact height of fall and corresponding impact which the slab would resist. The difficulty was caused by the fact that the slab would resist the 500 blows from a given height and crack and begin to settle very soon after the height of fall was increased. Thus while it can be said with certainty that the slab resisted the lesser impact and failed under the greater, the least impact which would have caused failure was not ascertained, and it can only be said that it lies between the values corresponding to the two heights of fall. In other cases, slabs would resist several hundred blows from a given height and then break. In such cases the exact height of the drop that caused the failure could be ascertained by adding to the height of fall at the beginning of the series of 500 drops during which the failure occurred, the settlement of the slab which occurred after the height was increased. For example, if a slab failed at 900 blows the height of fall at failure was determined by adding to the height of fall as measured by the autographic curve at 750 blows the center settlement which occurred between 750 and 900 blows.

The most difficult cases to interpret were those of the bituminous-filled brick sections which failed by cracking of the base under the one-eighth inch drop. The difficulty in these cases was due to the fact that there was no discernable crack and the height of fall which caused failure could only be assumed from a study of the rate of settlement.

In adopting the first crack as the criterion of failure it is necessary to remember that the character of the failure and the behavior of the pavement after initial cracking also give important indications of the value of the slab. Cracks in a rigid surface might not be injurious so long as it is not broken into small pieces by continued pounding. The bearing value of the subgrade must also be considered in interpreting the results of the tests.

THE TEST DATA EXPLAINED.

For purposes of comparison the various sections are grouped into four general divisions according to type of construction as follows:

1. Concrete surfaces.
2. Monolithic brick surfaces.
3. Brick surfaces on concrete bases with 1-inch sand-cement cushions.
4. Brick surfaces on concrete, macadam, and earth bases with sand and screening cushions.

The various sections in each group are compared with each other, but no attempt has been made to compare pavements of different type.

For each group a table has been prepared which gives in concise form the data necessary for the comparison of the several sections comprising the group. (See Tables 1, A, B, C, and D.) The height of fall given in these tables is the maximum drop which the slab resisted and corresponds to the forces given in the column headed "Computed resistance." The values given in the column headed "Failure" correspond to the height of fall which was observed to cause failure. Where it could be ascertained that the drop at which

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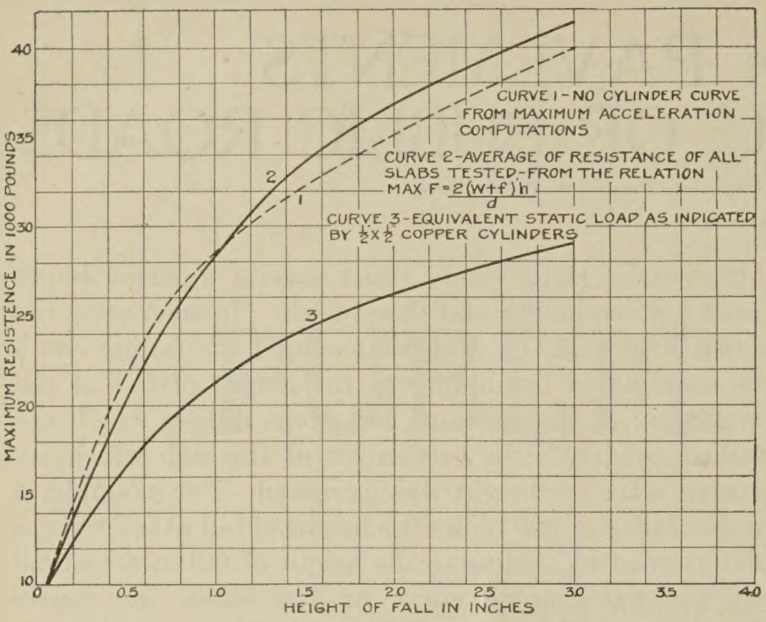


FIG. 1.—CURVES SHOWING THE RELATION OF COMPUTED VALUES OF STATIC EQUIVALENT LOADS AND THE STATIC EQUIVALENTS AS MEASURED BY COPPER CYLINDERS.

failure occurred was the least that would produce the result the figures given in the two columns are identical. Both sets of values are taken from curve 2 (fig. 1) which expresses the relation between height of fall and impact force. The methods by which the penetration index of subgrade bearing value and the moisture content were determined were described in the preceding article.

In addition to the tabular comparisons the condition of each section after failure is shown by means of photographs in figures 2, 3, 4, 5, and 6; the settlement of the various sections under the blows is shown in the curves of figure 7; and a brief paragraph is given to a description of the behavior of each section under test.

COMPARISON OF CONCRETE SURFACES.

In this group of sections are slabs 2, 4, 6, 8, and 10 inches thick. Their center settlement curves are shown in figure 7 and the figures representing their resistance to impact are given in table 1A. Photographs of representative failures are shown in figure 2.

Section No. 18. Concrete, 1 : 1½ :3 mix, 2 inches thick, on wet subgrade. This slab was not tested. It cracked through the middle before the test could be made. The fact that three concrete beams each 1 foot wide and 6 inches thick, with a total weight of approximately 1,000 pounds, rested on the slab during the winter is possibly responsible for the failure.

Section No. 115. Concrete, 1 : 1½ : 3 mix, 2 inches thick, on dry subgrade. This slab offered little or no resistance to the ⅛-inch drop, developed the first crack after the tenth blow, followed by rapid punching out at the center. The condition which resulted after 51 blows is shown in the photograph, figure 2. It can be said that the slab resisted 7,800 pounds static load, the weight of the plunger. The settlement of 1 inch occurred after 30 blows. It can readily be seen that a surface of this thickness can be of little value for road purposes.

Section No. 17. Concrete, 1 : 1½ :3 mix, 4 inches thick, on wet subgrade. This slab received a total of 634 blows, 500 beginning with ⅛-inch drop and 134 beginning with ½-inch. Although cracks were not observed until after the five hundredth blow it is evident from the curve, figure 7, that failure commenced somewhere between 250 and 500 blows. This failure is assumed to have occurred on a 0.204-inch drop, which was the height of fall at the four hundredth blow, the corresponding force for which is 14,900 pounds. The result after 634 blows was a badly broken slab with the center punched out. Settlement of 1 inch occurred after 600 blows.

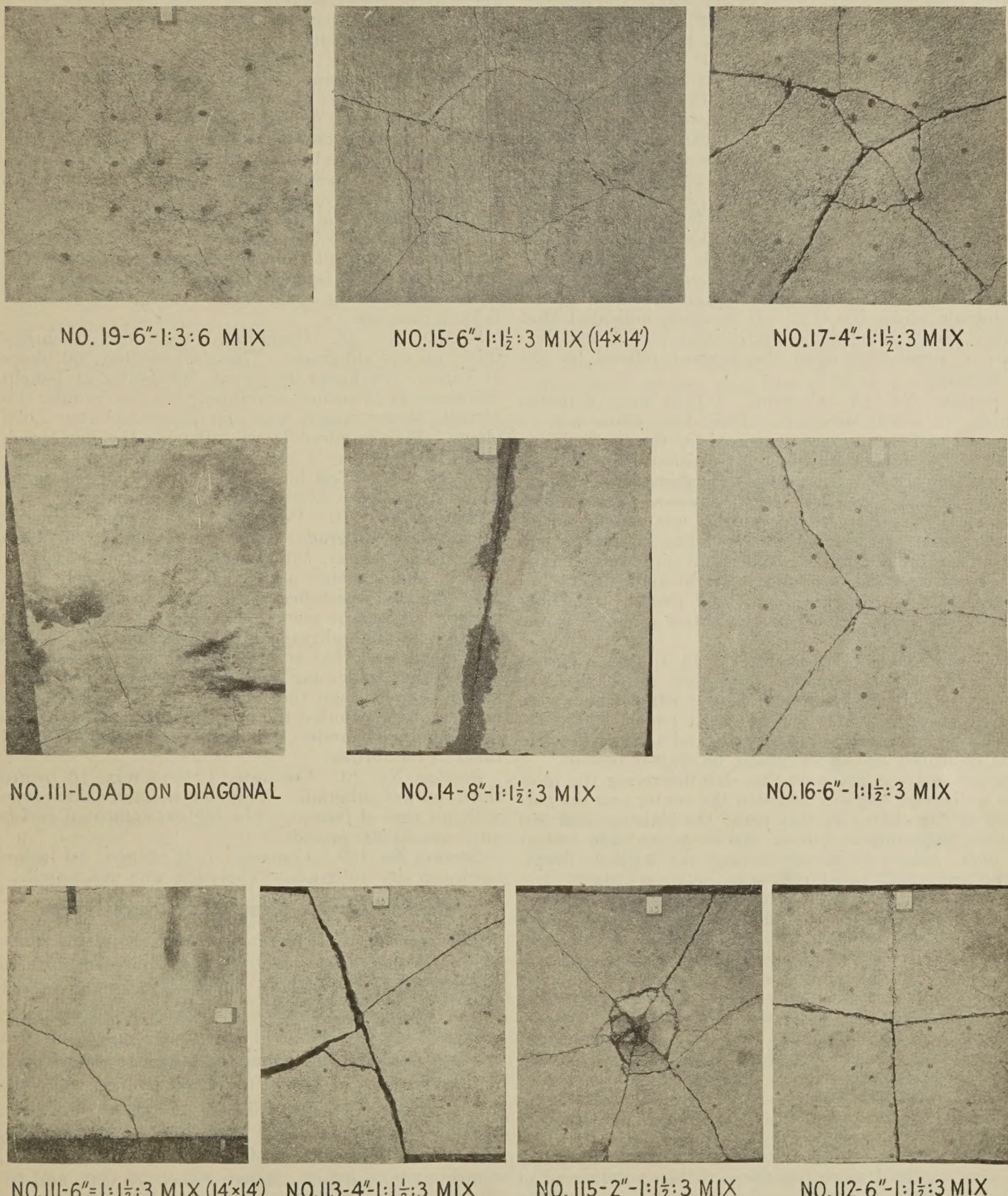
Section No. 113. Concrete, 1 : 1½ :3 mix, 4 inches thick, on dry subgrade. This slab withstood 500 blows beginning with ⅛-inch drop, and failed during 441 blows beginning with ½-inch; the first crack was observed after the five hundred and fortieth blow. The actual resistance was somewhere between 12,800 and 20,400 pounds, the values corresponding to the total drop at the end of the first 500 blows and the ½-inch drop, respectively. Settlement of 1 inch occurred after 770 blows. From both curves and photographs it can be seen plainly that No. 113 offered considerably more resistance than No. 17. Since the two slabs are of the same mix and thickness, the difference in their behavior must be due to the difference in support offered by the subgrades. Table 1–A shows that the penetration of the bearing value determinator was 2.15 inches around No. 17 and only 1.15 around No. 113. The rates of settlement as shown by the curves also indicate that there was better support under No. 113 than under No. 17. Consequently it was to be expected that the former would show the greater resistance.

TABLE 1–A.—*Tests of concrete surfaces.*

Slab No.	Size.	Thickness.	Mix.	Per cent of moisture.	Bearing value, penetration 50 blows.	Computed resistance.	Height of fall.	Force at failure.
	Feet.	*Inches.*			*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
18	7 x 7	2	1–1½–3	....	....	....	....	....
115	7 x 7	2	1–1½–3	18.4	1.50	7,800	....	....
17	7 x 7	4	1–1½–3	21.2	2.15	14,000	0.204	14,000
113	7 x 7	4	1–1½–3	18.4	1.15	12,800	.162	20,400
16	7 x 7	6	1–1½–3	21.2	1.92	23,700	.677	26,700
15	14 x 14	6	1–1½–3	....	....	42,400	3.000	42,400
112	7 x 7	6	1–1½–3	20.2	2.67	21,600	.555	26,700
						28,000	.975	31,300
111	14 x 14	6	1–1½–3	22.7	3.20	38,900	2.410	....
						23,900	.688	26,700
19	7 x 7	6	1–3 –6	21.2	3.31	21,900	.575	26,700
124	7 x 7	6	1–3 –6	20.1	2.40	13,200	.171	20,400
14	7 x 7	8	1–1½–3	....	2.65	33,000	1.420	34,700
110	7 x 7	8	1–1½–3	20.4	1.97	39,200	2.480	....
13	7 x 7	10	1–1½–3	22.8	2.11	39,200	2.480	....

Section No. 16. Concrete, 1:1½:3 mix, 6 inches thick, on wet subgrade. This slab resisted 500 blows beginning with ⅛-inch drop and 500 blows beginning at ½-inch. It failed under the ⅞-inch blows, the first crack developing soon after the one hundredth blow, at that height with the center settling rapidly under the following 239 blows. The resistance is indicated as being between 23,700 and 26,700 pounds. Settlement of 1 inch occurred after 1,160 blows.

Section No. 112. Concrete, 1:1½:3 mix, 6 inches, thick, on dry subgrade. This slab resisted 500 blows beginning at ⅛-inch drop, 500 blows beginning at ½-inch, and failed under the ⅞-inch blows with the first crack developing at the eleven hundred and seventy-fifth blow, followed by a second crack and resulting in the



NO. 19-6"-1:3:6 MIX

NO. 15-6"-1:$1\frac{1}{2}$:3 MIX (14'×14')

NO. 17-4"-1:$1\frac{1}{2}$:3 MIX

NO. 111-LOAD ON DIAGONAL

NO. 14-8"-1:$1\frac{1}{2}$:3 MIX

NO. 16-6"-1:$1\frac{1}{2}$:3 MIX

NO. 111-6"=1:$1\frac{1}{2}$:3 MIX (14'×14') LOAD AT CORNER

NO. 113-4"-1:$1\frac{1}{2}$:3 MIX

NO. 115-2"-1:$1\frac{1}{2}$:3 MIX

NO. 112-6"-1:$1\frac{1}{2}$:3 MIX

FIG. 2.—CONCRETE PAVEMENT SECTIONS.

condition shown in the photograph, figure 2, after the fourteen hundred and fourteenth blow. The indicated resistance lies between 21,600 and 26,700 pounds. Settlement of 1 inch occurred after 1,300 blows. The curves show that during the first 1,000 blows settlement was greater for No. 16, but that after cracks developed the settlement was greater for No. 112. It is of interest to note that after the principal cracks developed the resulting blocks resisted the blows without additional breaking. No. 16 can be considered as having shown slightly greater resistance than No. 112; first, because it received blows of greater force during the second 500 drops than No. 112 and also because it broke into but three instead of four pieces. It will be noted in Table 1–A, that the moisture content was greater in the subgrade of No. 16, while, contrary to what might be supposed, the supporting power is also indicated as being somewhat better than that of the subgrade under No. 112. It is again indicated that other things being equal the resistance of a road surface is dependent upon the support offered by the subgrade.

Section No. 15. Concrete, 1:1½:3 mix, 6 inches thick, on a wet subgrade. This slab, which was 14 instead of 7 feet square, was used for the first calibration of the impact machine. It resisted drops of from 0 to 3½ inches at a time when the subgrade was apparently frozen. The first crack, however, was noticed after a 3-inch drop, when the frost was coming out of the ground. The force corresponding to this 3-inch drop is 41,400 pounds. When the first cross crack occurred a second developed at right angles to it, followed by two diagonal cracks and then by punching out of the center. The final condition is shown in the photograph.

Section No. 111. Concrete, 1:1½:3 mix, 6 inches thick, on a dry subgrade. This slab, which also was 14 feet square, resisted 6,000 blows, 500 of which were at ⅛-inch drop, 500 at ½-inch, 500 at ⅞-inch, 500 at 1¼-inch, 500 at 1⅝-inch, 500 at 2-inch, and 3,000 at 2⅜-inch. Its indicated resistance would be 38,900 pounds. A second test was made on this slab delivering the blow on a diagonal halfway between the center and the corner of the slab. At this point the slab resisted 500 blows beginning at ⅛-inch, 500 at ½-inch, and 500 at ⅞-inch, failure occurring during the 1¼-inch drops. The indicated resistance was between 28,000 and 31,300 pounds, while a settlement of 1 inch occurred after 1,810 blows. The photograph, figure 2, shows the condition resulting after 2,150 blows. A third test was made by delivering blows on the extreme corner of the slab. At this point the slab resisted 500 blows at ⅛-inch, 500 at ½-inch, and failure resulted during the ⅞-inch drops. The indicated resistance was between 23,900 and 26,700 pounds, with a 1-inch settlement after 1,260 blows. The photograph shows the condition after this settlement. This failure consisted of a break across the corner. While it is impossible to compare the two 14-foot sections, it can be seen that they offered considerably greater resistance than the 7-foot sections. It was also indicated that the larger sections offered more resistance to blows delivered at their quarter points than the 7-foot sections at the center, while to blows delivered at the extreme corner the 14-foot sections showed about the same resistance as the 7-foot sections at their center.

Section No. 124. Concrete, 1 : 3 : 6 mix, 6 inches thick, on a dry subgrade. This slab resisted 500 blows at ⅛-inch and failed under ½-inch blows. The indicated resistance was between 13,200 and 20,400 pounds. The slab received a total of 734 blows. It will be noted that this slab showed considerably less resistance than the 1 : 1½ : 3 specimens.

Section No. 19. Concrete, 1 : 3 : 6 mix, 6 inches thick, on wet subgrade. This slab resisted 500 blows at ⅛-inch, 500 blows at ½-inch, and failed under ⅞-inch blows. One of the photographs shows the result after the one thousand and seventy-third blow. The indicated resistance lies between 21,900 and 26,700 pounds. Settlement of 1 inch occurred after 1,080 blows. It will be noted that radial cracks have developed in this section, which as a rule are preliminary to punching out of the center. This condition would indicate less resistance to impact than one in which only three or four blocks were formed; but in other respects this slab seems to be the equal of No. 112, the 6-inch slab of 1 : 1½ : 3 concrete.

Section No. 14. Concrete, 1 : 1½ : 3 mix, 8 inches thick, on wet subgrade. This slab resisted 500 blows at ⅛-inch, 500 blows at ½-inch, 500 blows at ⅞-inch, 500 blows at 1¼-inches, developing one crack under the 1⅝-inch blows, which was first observed after 2,050 blows. Five hundred blows following the first crack failed to produce a second. Settlement of 1 inch occurred after 2,580 blows. The indicated resistance would lie between 33,000 and 34,700 pounds.

Section No. 110. Concrete, 1 : 1½ : 3 mix, 8 inches thick, on dry subgrade. This slab resisted 6,000 blows without any cracks; 500 at each of the drops of ⅛, ½, ⅞, 1¼, 1⅝, and 2 inches and 3,000 at the 2⅜-inch drop. The indicated resistance at this drop would be 39,200 pounds. It can be seen from Table 1–A that the penetration of the subgrade around section No. 14 was 2.65 inches and that around section No. 110 was 1.97 inches, thus indicating that the latter received much better support than the former. To this better support can be attributed the fact that the latter failed to develop cracks under the same drops which caused them in the former.

Section No. 13. Concrete, 1 : 1½ : 3 mix, 10 inches thick, on wet subgrade. This slab resisted 6,000 blows with no sign of failure. The highest indicated resistance was 39,200 pounds.

Section No. 109. Concrete, 1 : 1½ : 3 mix, 10 inches thick, on dry subgrade. This slab was not tested.

SUMMARY OF THE TESTS OF CONCRETE SLABS.

The tests of the concrete sections show that slabs of 2-inch thickness are impractical for road surfaces and that slabs 4 inches in thickness can barely resist the static load of the heavier trucks without cracking, so that they surely would fail under impact of such trucks. It is indicated that the 6-inch types are good for a resistance of 21,000 to 24,000 pounds while the 8-inch are good for about 34,000 pounds on subgrades of no less supporting power than those of the test slabs. The indicated resistances of the slabs are 2-inch, 7,800; 4-inch, 14,000; 6-inch, 24,000; 8-inch, 34,000; and 10-inch, something over 40,000 pounds. It is shown that in all cases the slab resistance is dependent upon the support offered by the subgrade. Another indication seems to be that the resistance is overcome by the magnitude rather than the repetition of the blows. Considerable variation was shown between the two 6-inch 1:3:6 slabs, but the low resistance shown by No. 124 and the radial cracks which formed in No. 19 seem to indicate that they are not as strong as the 1:1½:3 specimens.

COMPARISON OF MONOLITHIC BRICK SECTIONS.

The sections in this group have grouted-brick surfaces with ¼-inch sand-cement cushions laid on green concrete bases. The combined concrete and brick slabs range in thickness from 5 to 10 inches. The center settlement curves are shown in figure 7, while representative failures appear in figure 3. Table 1–B gives the indicated resistances.

Section No. 24. Four-inch wire cut lug brick, laid on a 1:3:6 base, 1 inch thick, wet subgrade. This slab resisted 500 blows, beginning with ⅛-inch and failed under ½-inch blows. The curve, figure 7, shows the settlement after 617 blows. The indicated resistance lies between 16,800 and 20,400 pounds.

Section No. 22. Four-inch wire cut lug brick, laid on a 1:3:6 base, 2 inches thick, wet subgrade. This slab withstood 500 blows, beginning with ⅛-inch drop, 500 blows, beginning with ½-inch, and broke up rapidly under 144 blows, beginning at ⅞-inch. The indicated resistance was between 22,300 and 26,700 pounds. The views of the top and base (fig. 3) show the inability of a surface of this thickness to withstand the forces to which it was subjected. This point is clearly brought out by the badly shattered condition of the base.

Section No. 129. Four-inch wire cut lug brick, laid on a 1:3:6 base, 2 inches thick, dry subgrade. This slab resisted 500 blows at ⅛-inch drop and 163 blows at ½-inch, after which a badly broken condition resulted with the succeeding 59 blows. The indicated resistance was 20,400 pounds. Like No. 22, the base of this slab was also badly shattered. A comparison of the two slabs shows, however, that No. 129 offered less resistance than No. 22. As the possible explanation we find, by reference to Table 1–B, that the bearing power of the subgrade under No. 22 seems to be considerably greater than that of No. 129. In No. 129

TABLE 1–B.—*Tests of monolithic brick sections, with one-quarter inch sand-cement cushion.*

Slab No.	Base. Thickness.	Base. Mix.	Cushion.	Surface. Thickness.	Surface. Type.	Per cent of moisture.	Bearing value, penetration 50 blows.	Computed resistance.	Height of fall.	Force at failure.
	Inches.			*Inches.*			*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
25	4	1–3–6	¼-inch sand-cement	4	Wire cut lug	27.6	2.50	31,500	1.27	31,500
128	4	1–3–6	....do	4	....do	(1)	(1)	(1)	(1)	(1)
121	4	1–3–6	....do	4	Repressed	19.8	1.49	28,300	.99	31,300
123	4	1–3–6	....do	3½	Vertical fiber	18.3	2.35	21,000	.53	21,000
21	4	1–3–6	....do	3	Wire cut lug	21.2	2.46	26,900	.703	26,900
118	4	1–3–6	....do	3	....do	18.0	1.84	21,400	.55	26,700
23	6	1–3–6	....do	4	....do	21.0	2.76	39,700	2.58	....
126	6	1–3–6	....do	4	....do	(1)	(1)	(1)	(1)	(1)
120	6	1–3–6	....do	4	Repressed	(1)	(1)	(1)	(1)	(1)
122	6	1–3–6	....do	3½	Vertical fiber	(1)	(1)	(1)	(1)	(1)
20	3	1–3–6	....do	3	Wire cut lug	21.3	2.58	12,000	.13	20,400
119	3	1–3–6	....do	3	....do	18.8	1.68	12,200	.14	20,400
22	2	1–3–6	....do	4	....do	23.5	2.86	22,300	.50	26,700
129	2	1–3–6	....do	4	....do	23.2	3.25	20,400	.50	20,400
24	1	1–3–6	....do	4	....do	23.9	2.48	16,800	.33	20,400
127	1	1–3–6	....do	4	....do	23.0	2.68	18,300	.40	20,400

[1]Not tested.

Section No. 127. Four-inch wire cut lug brick, laid on a 1:3:6 base, 1 inch thick, dry subgrade. This slab was subjected to 1,200 blows. It resisted 1,000 blows, beginning with the ⅛-inch drop. The first crack was observed after 500 blows. Settlement, however, remained uniform through the next 500 blows with rapid breaking up during the last 200. The indicated resistance was 18,300 pounds. Table 1–B shows that there is little difference between the moisture content and bearing power of the two subgrades to account for the difference in the behavior of these two slabs of the same construction. It is possible that the difference may have been caused by separation of the base and top in one section before the other. It is also to be remarked that the first crack in No. 127 occurred under a number of repeated blows at approximately the same height of fall rather than after a change in the height of fall. This type of failure, which seems to be common with monolithic construction, can be explained by the fact that up to a certain point the slab acts as a monolith, but after a number of repeated blows the brick is separated from the concrete base, resulting in two slabs, the combined resistance of which is not greater than the sum of resistance of the two parts.

we find again that failure occurred because of the separation of the base from the top and the immediate breaking up of the resulting two slabs.

Section No. 20. Three-inch wire cut lug brick laid on a 1:3:6 base, 3 inches thick, wet subgrade. This slab resisted 500 blows at ⅛-inch drop and was badly broken under 520 blows, beginning with ½-inch. The indicated resistance lies between 12,000 and 20,400 pounds.

Section No. 119. Three-inch wire cut lug brick laid on a 1:3:6 base, 3 inches thick, dry subgrade. This slab resisted 500 blows at ⅛-inch drop and was badly broken under 500 blows, beginning with ½-inch. The indicated resistance lies between 12,200 and 20,400 pounds. Although the subgrade under No. 119 was better than that under No. 20, there seems to be little difference in the resistance offered by the two slabs. Again, it is evident that instead of acting as a monolith this section simply acted as two independent 3-inch slabs.

Section No. 21. Three-inch wire cut lug brick, laid on a 1:3:6 base, 4 inches thick, wet subgrade. This slab resisted 500 blows at ⅛-inch drop, 500 blows at ½-inch, and 250 at ⅞-inch, breaking up under 395 addi-

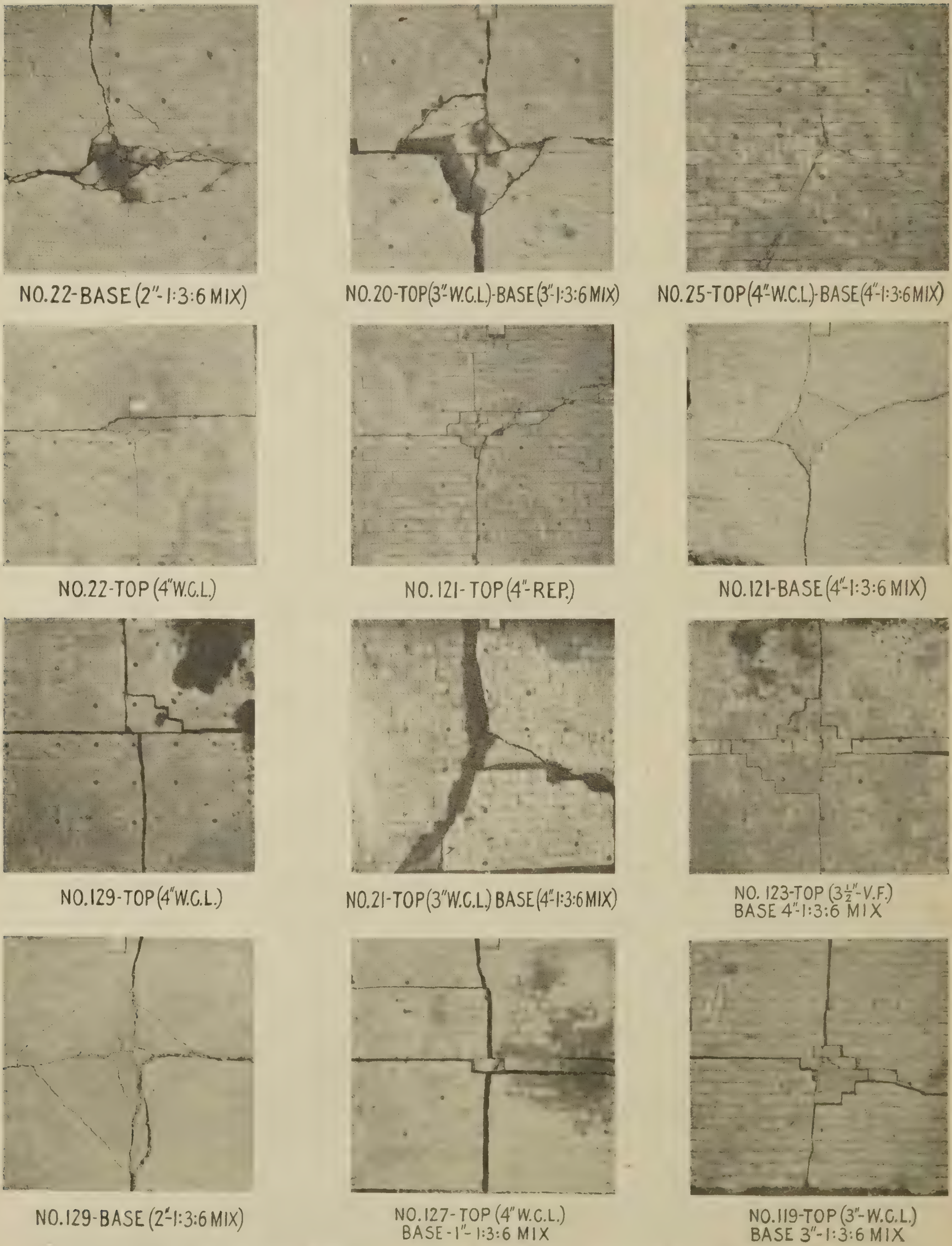


FIG. 3.—BRICK TOPS ON CONCRETE BASES WITH 3/16-INCH SAND-CEMENT CUSHIONS (MONOLITHIC CONSTRUCTION).

tional blows beginning at $\frac{7}{8}$-inch. The indicated resistance was 26,900 pounds. Again, it is noted that failure occurred because of the separation of the two parts of the surface under repeated blows of approximately the same height.

Section No. 118. Three-inch wire cut lug brick, laid on a 1 : 3 : 6 base, 4 inches thick, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch and 500 blows at $\frac{1}{2}$-inch, failing under the $\frac{7}{8}$-inch blows, showing a cracked and settled condition at the end of 442 blows from that height. The indicated resistance lies between 21,400 and 26,700 pounds. This slab offered about the same resistance as No. 21 although in this case the top did not separate from the base during the run of 500 blows.

Section No. 123. Three and one-half inch vertical fiber brick, laid on a 1 : 3 : 6 base, 4 inches thick, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 410 blows beginning with $\frac{1}{2}$-inch, rapidly breaking up under 149 succeeding blows. The indicated resistance was 21,000 pounds. Again, the behavior of the section was characterized by separation of the two parts of the surface under repeated blows followed by rapid failure.

Section No. 25. Four-inch wire cut lug brick, laid on a 1 : 3 : 6 base, 4 inches thick, wet subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, 500 blows at $\frac{7}{8}$-inch, 250 blows at $1\frac{1}{4}$-inch, resulting in the condition shown by the photograph (fig. 3) after 713 additional blows. The indicated resistance was 31,500 pounds.

Section No. 121. Four-inch repressed brick, laid on a 1 : 3 : 6 base, 4 inches thick, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, and 500 blows at $\frac{7}{8}$-inch, breaking up under 384 blows at $1\frac{1}{4}$ inches. The indicated resistance was between 28,300 and 31,300 pounds. Although the subgrade of No. 121 indicated better bearing power than that of No. 25 the latter showed more resistance than the former.

Section No. 23. Four-inch wire cut lug brick, laid on a 1 : 3 : 6 base, 6 inches thick, wet subgrade. This slab resisted 6,000 blows, 500 at each of the $\frac{1}{8}$, $\frac{1}{2}$, $\frac{7}{8}$, $1\frac{1}{4}$, $1\frac{5}{8}$, and 2 inch drops and 3,000 at $2\frac{3}{8}$ inches without showing any signs of failure. The indicated resistance at the $2\frac{3}{8}$-inch drop was 39,700 pounds.

SUMMARY OF THE TESTS OF MONOLITHIC BRICK SECTIONS.

In general, it can be seen from the above results that the resistance of monolithic slabs is an uncertain quantity, the uncertainty being caused by the fact that the slab acts as a monolith up to a certain point, after which it becomes two independent slabs, when a resistance equal only to the sum of the strengths of the two parts can be expected if top and bottom break at the same instant. If, however, the weaker part breaks before the stronger, then a resistance equal only to that of the latter can be expected. Several of the monolithic slabs indicated that resistance to horizontal shear was greater than the sum of the resistances of top and base in bending.

Slab numbers 22, 25, and 23 indicated resistances slightly greater than would be expected from the two parts of the slabs acting as units but breaking at the same instant. This would indicate excellent adhesion, which resisted horizontal shear between tops and bases. Nos. 118, 121, and 24 showed resistances equal to the sums of the strengths of the tops and bases when acting as units but breaking at the same instant. Nos. 129, 119, 21, 123, and 127 indicated that horizontal shear had developed and the weaker course failed in bending before the stronger, thus showing resistances slightly less than the sum of the two parts.

COMPARISON OF BRICK SURFACES AND SAND-CEMENT AND TAR-MASTIC CUSHIONS.

In this group are grout and bituminous filled brick surfaces with 1-inch sand-cement and $\frac{1}{2}$-inch tar-mastic cushions on concrete bases. Representative failures are shown in figures 4 and 5, while indicated resistances are given in Table 1–C and curves of center settlement in figure 7.

Section No. 8. Four-inch wire cut lug brick, grout filled, on a 1-inch sand-cement cushion and 4-inch 1 : 3 : 6 base, wet subgrade. This slab resisted 1,000 blows at the $\frac{1}{8}$-inch drop. It developed two cracks and settlement during 990 blows, beginning at the $\frac{1}{2}$-inch drop. From the photographs, figure 4, it can be noted that the center did not punch out either in top or foundation. The indicated resistance lies between 18,400 and 20,400 pounds.

Section No. 106. Four-inch wire cut lug brick, grout filled, on 1-inch sand-cement cushion and 4-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, and 500 blows at $\frac{7}{8}$-inch. It developed the first crack after 375 blows, beginning at the $1\frac{1}{4}$-inch drop, resulting in settlement and the condition shown by the curves and photographs through 1,315 additional drops. The indicated resistance was 31,600 pounds. It will be noted that this slab acted very much like the monolithic sec-

TABLE 1–C.—*Tests of grout and bituminous filled brick surfaces on concrete bases and either 1-inch sand-cement or one-half-inch tar-mastic cushions.*

Slab No.	Thickness of 1–3–6 concrete base.	Cushion.	Surface. Thickness.	Surface. Type.	Per cent of moisture.	Bearing value, penetration 50 blows.	Computed resistance.	Height of fall.	Force at failure.
	Inches.		*Inches.*			*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
7	6	1-inch sand-cement	4	Wire cut lug, grout filled	25.0	3.12	26,400	.85	31,300
105	6	.....do	4	.....do	19.7	3.62	31,800	1.30	34,700
10	6	.....do	$3\frac{1}{2}$	Vertical fiber, asphalt filled	25.2	4.40	24,600	.733	26,700
103	6	.....do	$3\frac{1}{2}$	.....do	19.7	3.71	26,700	.53	26,700
8	4	.....do	4	Wire cut lug, grout filled	22.6	3.49	18,400	.39	20,400
106	4	.....do	4	.....do	17.7	1.89	31,600	1.29	31,600
4	4	.....do	$3\frac{1}{2}$	Vertical fiber, asphalt filled	23.9	5.94	13,300	.18	13,300
2	4	$\frac{1}{2}$-inch tar-sand	4	Wire cut lug, tar-sand filled	21.2	2.43	14,000	.21	20,400
116	6	.....do	4	.....do	.....	.....	26,800	.88	26,800

tions. Considerably more resistance was shown by No. 106 than by No. 8, and from the bearing power values, as shown by Table 1–C, this was of course to be expected.

Section No. 7. Four-inch wire cut lug brick, grout filled, on a 1-inch sand-cement cushion and 6-inch 1 : 3 : 6 base, wet subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, 500 blows at $\frac{7}{8}$-inch, developing two cracks and settlement through 535 blows beginning with $1\frac{1}{4}$ inches. The indicated resistance lies between 26,400 and 31,300 pounds.

Section No. 105. Four-inch wire cut lug brick, grout filled, on a 1-inch sand-cement cushion and 6-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 at $\frac{1}{2}$-inch, 500 at $\frac{7}{8}$-inch, 500 at $1\frac{1}{4}$-inch, developing cracks and settlement through 615 blows beginning at $1\frac{5}{8}$ inches. The indicated resistance lies between 31,800 and 34,700 pounds. This slab on a dry subgrade showed greater resistance than its duplicate on the wet subgrade, although from the penetration test the dry subgrade seemed to offer less support than the wet, and notwithstanding that the moisture determinations showed considerably less moisture in the dry subgrade than in the wet.

Section No. 4. Three and one-half inch vertical fiber brick, asphalt filled, on a 1-inch sand-cement cushion and 4-inch 1 : 3 : 6 base, wet subgrade. This slab offered very little resistance, showing rapid punching out of the center through 365 blows, beginning at the $\frac{1}{8}$-inch drop. It is very difficult to say just what resistance was shown by it, but the assumption is made that failure occurred on the 0.18-inch drop with a resulting force of 13,300 pounds. Table 1–C shows an extremely bad condition of the subgrade around this slab.

Section No. 10. Three and one-half inch vertical fiber brick, asphalt filled, on a 1-inch sand-cement cushion and 6-inch 1 : 3 : 6 base, wet subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, developing cracks and settlement through 842 blows at $\frac{7}{8}$-inch. The resistance is assumed to lie between 24,600 and 26,700 pounds.

Section No. 103. Three and one-half inch vertical fiber brick, asphalt filled, on a 1-inch sand-cement cushion and 6-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, and developed cracks and settlement through 1,508 blows, beginning at $\frac{7}{8}$-inch. The indicated resistance is 26,700 pounds.

Section No. 2. Four-inch wire cut lug brick, tar-sand filler, on a $\frac{1}{2}$-inch tar-sand cushion and 4-inch 1 : 3 : 6 base, wet subgrade. This slab withstood 500 blows at $\frac{1}{8}$-inch drop, failing through 530 blows beginning at $\frac{1}{2}$-inch, the indicated resistance lying between 14,000 and 20,400 pounds.

Section No. 116. Four-inch wire cut lug brick, tar-sand filler, on a $\frac{1}{2}$-inch tar-sand cushion and 6-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, and 250 blows at $\frac{7}{8}$-inch, developing rapid settlement through the succeeding 510 blows. The estimated resistance is 26,800 pounds.

SUMMARY OF TESTS OF SEMIMONOLITHIC BRICK SECTIONS.

With one exception, the semimonolithic specimens showed less resistance than the monolithic. The exception was No. 106, which showed resistance equal to that of the sum of the top and base. In general, however, little relation could be discovered between the resistance and total thickness of the semimonolithic slabs. Their resistance is possibly affected by the adhesion between the surface and base. Until it is definitely shown that the surface of this type of pavement does not separate from the base, it would not be advisable to expect greater resistance than is offered by the sum of the strengths of the base and top.

COMPARISON OF BRICK SURFACES LAID ON SAND AND SCREENING CUSHIONS AND CONCRETE AND MACADAM BASES.

In this group are the grout and bituminous filled brick surfaces with sand and screening cushions laid on concrete and macadam bases. Representative failures are shown in figures 5 and 6, while the indicated resistances are given in Table 1–D. Center settlement curves are shown in figure 7.

Section No. 104. Three and one-half inch vertical fiber brick, asphalt filled, on 1-inch screening cushion and 4-inch 1 : 3 : 6 base, dry subgrade. This slab failed under load beginning with the $\frac{1}{8}$-inch drop. Its center was punched out during 568 drops. In this case it was assumed that the resisting force was equal to 15,000 pounds.

Section No. 6. Three and one-half inch vertical fiber brick, asphalt filled, on 1-inch sand cushion and 4-inch 1 : 3 : 6 base, wet subgrade. This slab resisted 500 blows beginning with $\frac{1}{8}$-inch drop and had its center punched out in the succeeding 104 blows at the same drop. The indicated resistance of this slab was 20,400 pounds.

Section No. 5. Three and one-half inch vertical fiber brick, asphalt filled, on 1-inch sand cushion and 6-inch 1 : 3 : 6 base, wet subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, developing cracks and settlement in the succeeding 735 blows beginning with $\frac{1}{2}$-inch. The estimated resistance was between 21,000 and 26,700 pounds.

Section No. 101. Three and one-half inch vertical fiber brick, asphalt filled, on 1-inch sand cushion and 6-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop, then failed during 608 blows, beginning at $\frac{1}{2}$-inch, there being considerable resistance during the first 250 blows at the latter height. The estimated resistance was 23,400 pounds.

Section No. 117. Three and one-half inch vertical fiber brick, asphalt filled, on 1-inch screening cushion and 6-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at $\frac{1}{8}$-inch drop and failed during 658 blows beginning at $\frac{1}{2}$-inch. The estimated resistance was between 14,900 and 20,400 pounds.

Section No. 125. Four-inch wire cut lug brick, grout filled, on a 1-inch screening cushion, no base, dry subgrade. This slab failed during 502 blows beginning with the $\frac{1}{8}$-inch drop. The indicated resistance was 14,800 pounds, which is about what can be expected from a 4-inch concrete surface.

Section No. 3. Four-inch wire cut lug brick, grout filled, on a 1-inch screening cushion and 6-inch macadam base, wet subgrade. This slab was damaged before test.

Section No. 1. Four-inch wire cut lug brick, grout filled, on a 1-inch screening cushion and 12-inch mac-

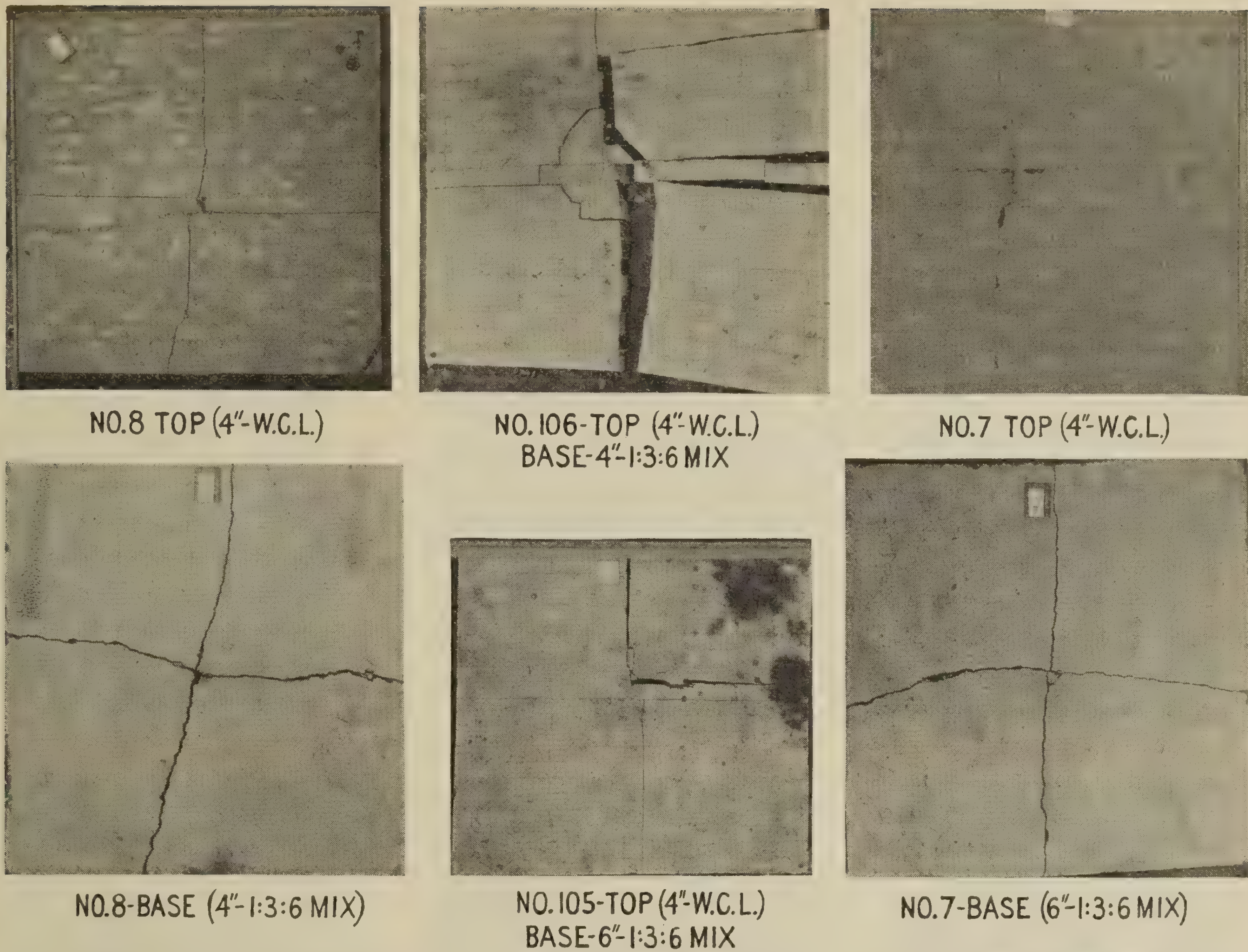


FIG. 4.—BRICK TOPS ON CONCRETE BASES WITH 1-INCH SAND-CEMENT AND ½-INCH TAR-MASTIC CUSHIONS (SEMI-MONOLITHIC CONSTRUCTION).

TABLE 1-D.—*Tests of brick surfaces with sand and screening cushions and concrete and macadam bases.*

Slab No.	Base.		Cushion.		Surface.		Per cent moisture.	Bearing value, penetration 50 blows.	Computed resistance.	Height of fall.	Force at failure.
	Thickness.	Material.	Thickness.	Material.	Thickness.	Type.					
	Inches.		*Inches.*		*Inches.*			*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
104	4	1-3-6 concrete	1	Screenings	3½	Vertical fiber, asphalt filled	19.4	2.20	15,000	0.25	15,000
9	6	do	1	Sand	4	Wire cut lug, grout filled	22.2	2.43	25,300	.78	26,700
11	6	do	1	do	4	do	22.8	1.80	23,900	.69	26,700
107	6	do	1	do	4	do	18.0	2.40	29,600	1.10	31,300
114	6	do	1	Screenings	4	do	18.2	2.19	28,700	1.03	31,300
117	6	do	1	do	3½	Vertical fiber, asphalt filled	17.2	1.53	14,900	.24	20,400
102	4	do	1	do	4	Wire cut lug, grout filled	16.0	1.96	12,800	.16	20,400
101	6	do	1	Sand	3½	Vertical fiber, asphalt filled	20.5	3.62	23,400	.66	23,400
5	6	do	1	do	3½	do	25.2	3.83	21,000	.53	26,700
6	4	do	1	do	3½	do	23.7	3.33	20,400	.50	20,400
12	4	do	1	do	4	Wire cut lug, grout filled	23.5	2.88	14,000	.21	20,400
125			1	Screenings	4	do	19.6		14,500	.23	14,500
1	12	Macadam	1	do	4	do	23.8	3.32	14,500	.23	20,400
130	12	do	1	do	4	do					
3	6	do	1	do	4	do	25.2	2.98	(1)	(1)	(1)
131	6	do	1	do	4	do					
108	4	do	1	Sand	4	do	17.8		13,800	.20	20,400

(1) Damaged.

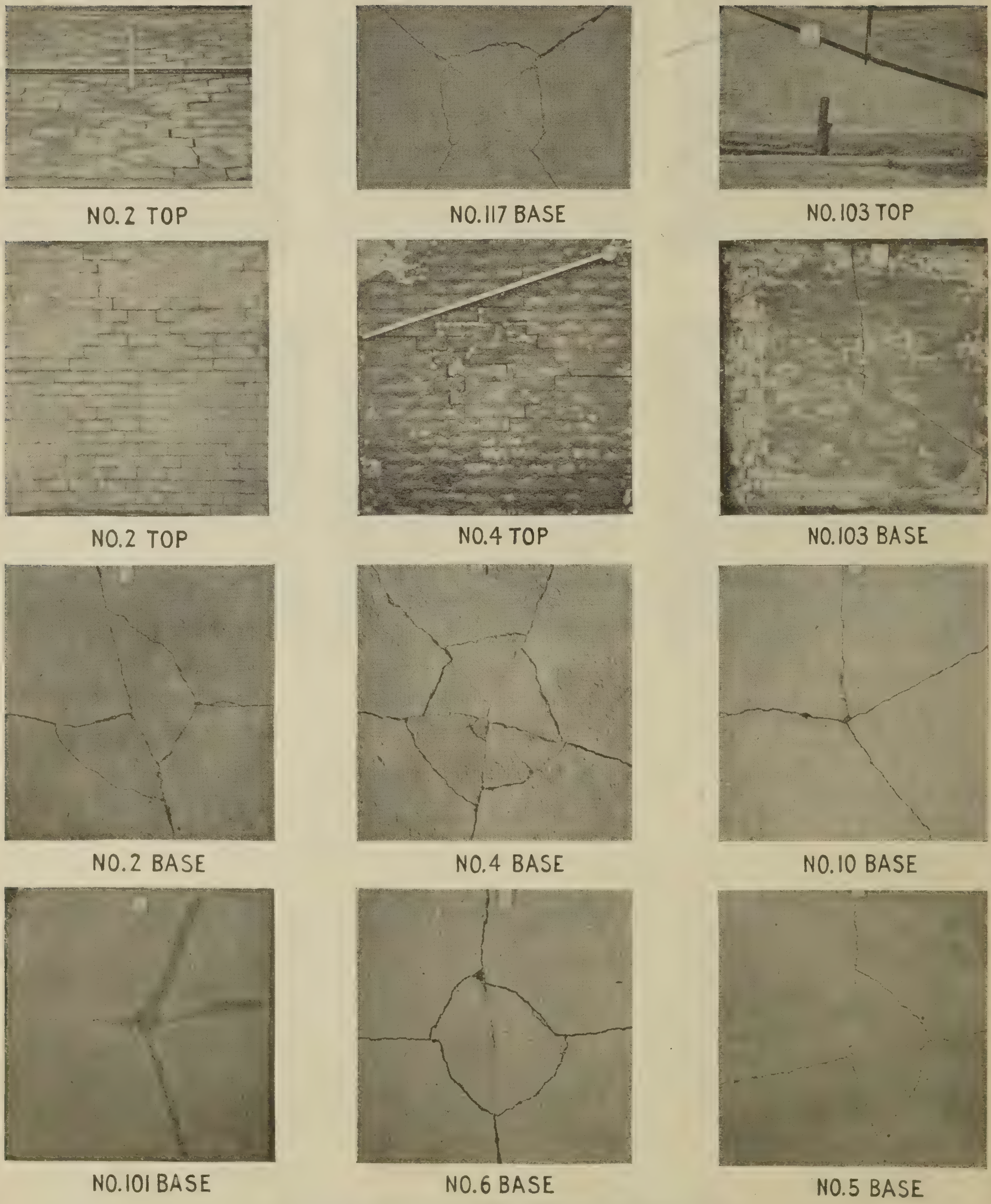
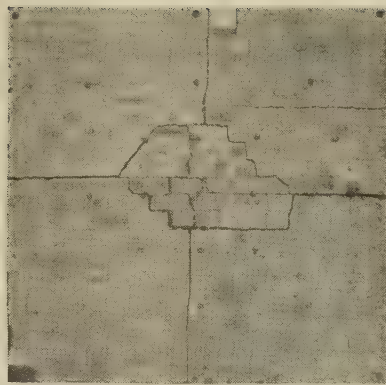
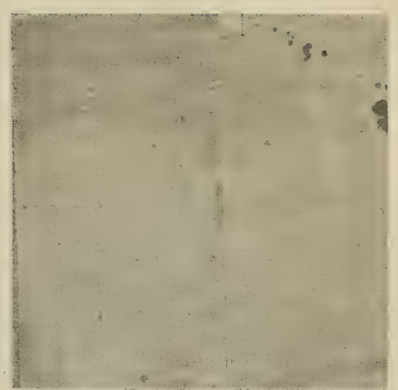


FIG. 5.—BITUMINOUS-FILLED BRICK TOPS ON CONCRETE BASES.

NO. 108 BASE



NO. 125 TOP

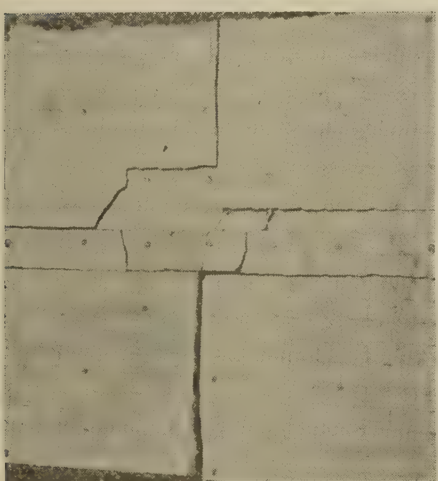


NO. 107 TOP

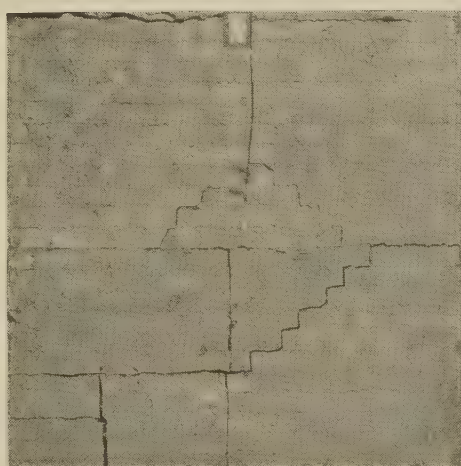
NO. 102 BASE

NO. 1 TOP

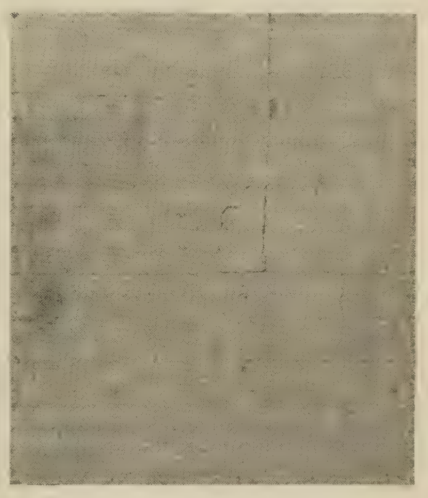
NO. 107 BASE



NO. 102 TOP



NO. 1 TOP



NO. 12 TOP

NO. 11 BASE

NO. 9 BASE

NO. 12 BASE

FIG. 6.—GROUTED BRICK TOPS ON CONCRETE AND MACADAM BASES.

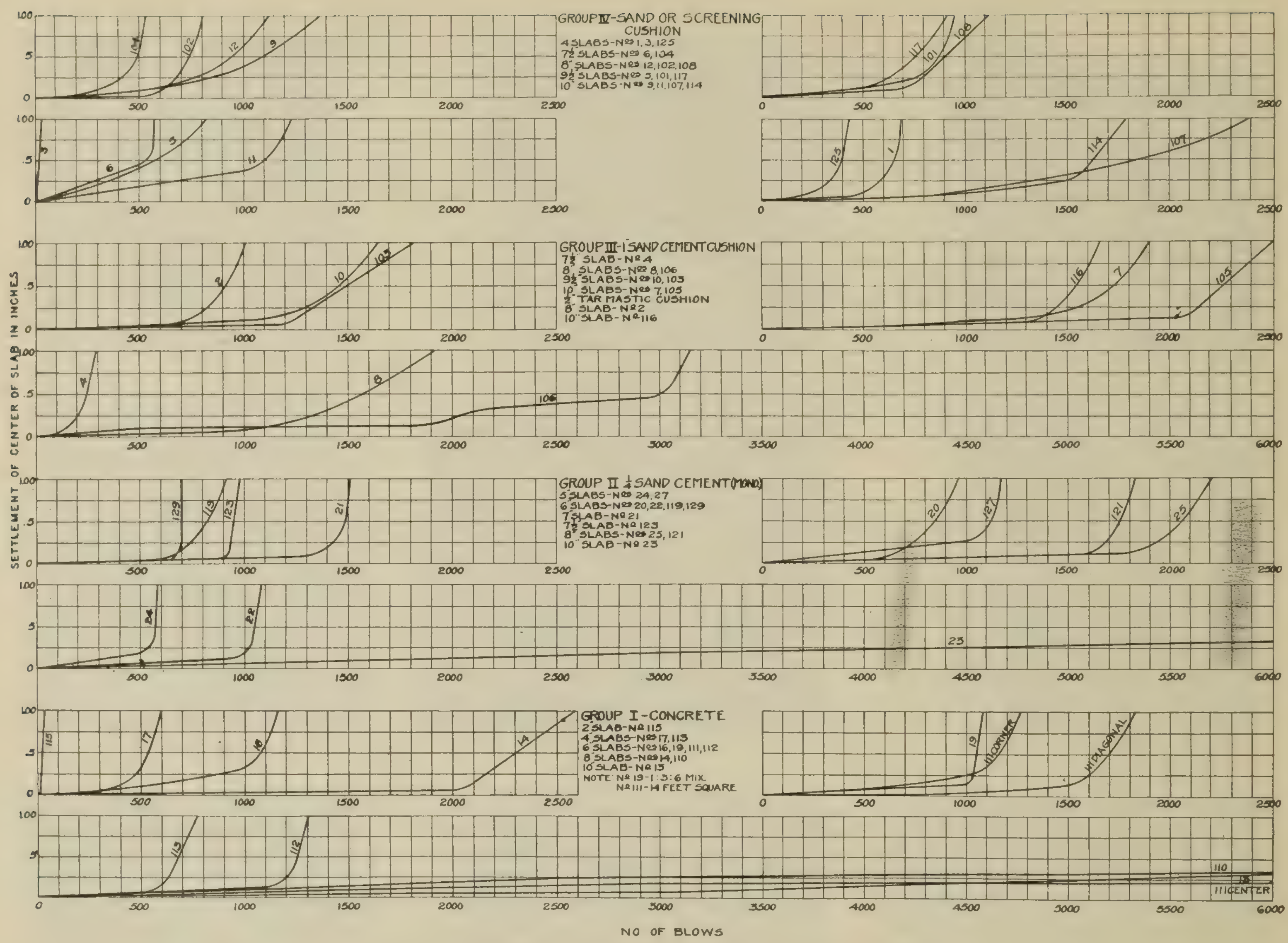


FIG. 7.—CENTER SETTLEMENT CURVES FOR ALL SLABS.

adam base, wet subgrade. This slab resisted 500 blows at ⅛-inch drop, and failed completely through 257 blows beginning at ½-inch. The estimated resistance was between 14,500 and 20,400 pounds.

The resistances offered by this last series of slabs were simply those which could be expected from the grouted brick slabs. The base condition can not be compared to that secured when brick is laid on an old gravel or macadam surface as a base. It is impossible to secure in a short time or with the implements used at Arlington the same degree of compaction which is obtained on an old road by years of traffic. Results given here for macadam bases therefore are not to be compared with those which would be derived from placing brick surfaces on an old roadbed.

Section No. 12. Four-inch wire cut lug brick, grout filled, on a 1-inch sand cushion and 4-inch 1 : 3 : 6 base, wet subgrade. This slab resisted 500 blows at ⅛-inch drop, cracked and settled under 500 blows beginning with ½-inch and 534 blows beginning at ⅞-inch. The indicated resistance lies between 14,000 and 20,400 pounds.

Section No. 108. Four-inch wire cut lug brick, grout filled, on a 1-inch sand cushion and 4-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at ⅛-inch drop and became badly broken through 890 blows beginning at ½-inch. The indicated resistance lies between 13,800 and 20,400 pounds.

Section No. 102. Four-inch wire cut lug brick, grout filled, on a 1-inch screening cushion and 4-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at ⅛-inch drop and was badly broken by 324 blows beginning at ½-inch. The estimated resistance lies between 12,800 and 20,400 pounds.

Section No. 9. Four-inch wire cut lug brick, grout filled, on a 1-inch sand cushion and 6-inch 1 : 3 : 6 base, wet subgrade. This slab resisted 500 blows at ⅛-inch drop, 500 blows at ½-inch, developing cracks and settlement through 661 blows beginning at ⅞-inch. The indicated resistance was between 25,300 and 26,700 pounds.

Section No. 11. Four-inch wire cut lug brick, grout filled, on a 1-inch sand cushion and 6-inch 1 : 3 : 6 base wet subgrade. This slab resisted 500 blows at ⅛-inch drop, 500 blows at ½-inch, developing cracks and settlement through 1,429 blows beginning with ⅞-inch. The estimated resistance lies between 23,900 and 26,700 pounds.

Section No. 107. Four-inch wire cut lug brick, grout filled, on a 1-inch sand cushion and 6-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at ⅛-inch, 500 blows at ½-inch, 500 blows at ⅞-inch, and cracked and settled through 740 blows at the 1¼-inch drop. The indicated resistance was between 29,600 and 31,300 pounds.

Section No. 114. Four-inch wire cut lug brick, grout filled, on a 1-inch screening cushion and 6-inch 1 : 3 : 6 base, dry subgrade. This slab resisted 500 blows at

$\frac{3}{8}$-inch drop, 500 blows at $\frac{1}{2}$-inch, 500 blows at $\frac{7}{8}$-inch, and cracked and settled through 500 blows at $1\frac{1}{4}$ inches. The indicated resistance lies between 28,700 and 31,300 pounds.

It can be seen plainly from the foregoing that little can be expected from the above type of construction except the resistance of the stronger part of the slab. Nos. 6, 107, and 114 seem to be exceptions. Also it is to be noted that considerably more settlement occurred before the first crack, caused possibly by the shifting of the sand and screening bed. It can not be seen that the cushioning effect of this sand bed in any way increases the resistance of the pavement.

Indications are that the grouted 4-inch brick surfaces are just as strong as the 4-inch concrete slabs. Also, in general, it would appear that the sections with bituminous-filled brick surfaces show less resistance than similar slabs with grout-filled brick.

RESISTANCES DETERMINED MEASURE BEAM STRENGTH OF SLABS.

It must be borne in mind that the resistances determined in the tests do not measure the strength of the slabs when supported uniformly by their subgrades. Though the slabs themselves settled under the repeated blows, the relatively inelastic subgrades were pounded down still further. As the test proceeded the space between the subgrade and slab became greater, permitting greater deflections of the slab until failure occurred. The resistances measured, therefore, indicate the strength of the sections acting as slabs with little or no support at their centers. They measure, in other words, what is commonly known as the "beam strength" of the slabs, and not their supported slab strength. Considering the conditions of the test the results are about what one would expect. A bituminous-filled brick slab would not be expected to show much beam strength, and a composite beam made up of parts which break separately and at different times could not be expected to show greater strength than the resistance of its strongest part. Very often the quality of "beam strength" is the factor which determines the serviceability of a road, but it must not be assumed that such is always the case.

SECTIONS OF PAVEMENT TESTED AS BEAMS.

As mentioned in the preceding article, it was thought that additional information might be obtained by constructing a series of beams representing the various slabs and determining their respective moduli of rupture when subjected to static loads centrally applied.

The beams, which were made in duplicate at the same time as the slabs, corresponded to the slabs in design and workmanship. Their depths varied with the type of pavement represented, in breadth they ranged from 12 to 13 inches, and all were exactly 7 feet in length. At the time they were tested they had been aged in the open for about one year.

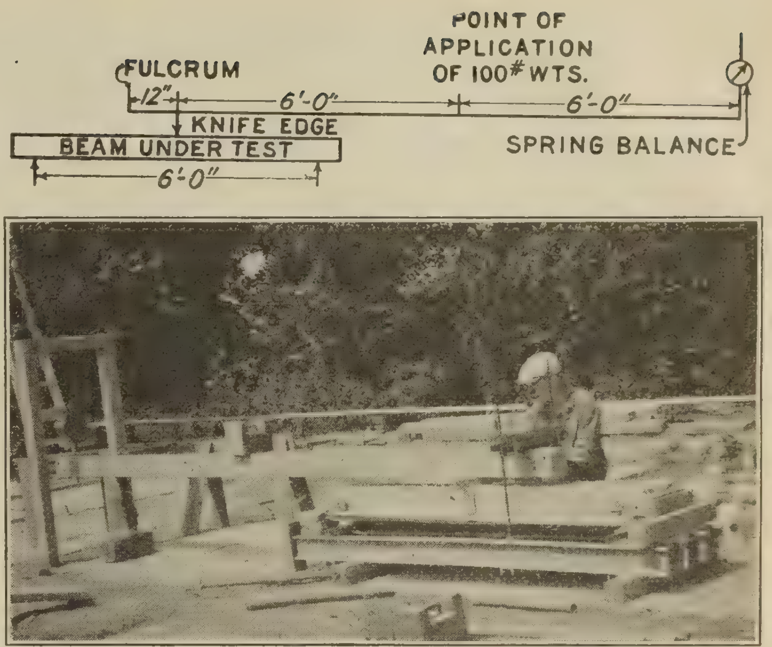


FIG. 8.—APPARATUS DEVISED TO TEST THE BEAMS.

The diagram and photograph, figure 8, show the special device arranged to test the beams and illustrate clearly the methods of support and loading, and the apparatus for measuring deflections. The loads applied and the indicated moduli of rupture are given in Table 2.

The most useful purpose served by the beam tests is the confirmation of the conclusions drawn from the slab tests relative to the behavior of the monolithic slabs. As shown by Table 2, the average modulus of rupture for 1 : $1\frac{1}{2}$: 3 concrete alone is 546 pounds per square inch; for 1 : 3 : 6 concrete it is 475; for grouted brick, 712 pounds per square inch; and for monolithic beams only 385 pounds, indicating that the full strengths of the concrete base and brick surface are not available when they are combined. The typical fractures, illustrated in figure 9, show how the tops of the monolithic beams shear from the bases under test, resulting in two independent beams. The resulting strength is shown by Table 2 to be somewhat greater than the sum of the strengths of the two parts. The only monolithic beams which showed a modulus of rupture approaching that of 1 : 3 : 6 concrete were those with a 2-inch base. The average for such beams was 465 pounds per square inch, while that of the concrete base alone was 475 pounds per square inch.

The low resistance shown by beams Nos. 47, 48, 49, and 50 (Table 2) are consistent with the behavior of the slabs under impact test, indicating that when there is a cushion, separating the top and the base, which allows one to break before the other, the strength is not proportional to the total thickness but rather to the thickness of the stronger part.

It will be noted that the average breaking loads for the 4, 6, 8, and 10 inch, 1 : $1\frac{1}{2}$: 3 concrete beams are 910, 1,940, 3,500, and 5,600 pounds, respectively, which follows the theory that the strength of a beam varies as the square of its depth. This relation is also shown

TABLE 2.—*Resistances of pavement sections tested as beams under static loads.*

No. of beam.	Description. Thickness of base.	Description. Mix.	Description. Thickness of surface.	Description. Type of surface.	Total load at center.	Modulus of rupture.
	Inches.		*Inches.*		*Pounds.*	*Lbs. per sq. in.*
1		1-1½-3 concrete	4		430	302
2		do	4		1,330	812
3		do	4		980	620
4		do	6		1,080	292
5		do	6		2,880	773
6		do	8		3,950	595
7		do	8		3,250	498
8		do	8		3,350	512
9		do	10		6,110	583
10		do	10		5,285	508
11		do	10		5,410	520
12		1-3-6 concrete	3		520	525
13		do	4		710	500
14		do	4		710	511
15		do	4		640	454
16		do	6		1,520	450
17		do	6		1,655	485
18			6		1,330	399
19			6		1,690	491
20			6		1,560	459
21	2	1-3-6 concrete	3½	Vertical fiber brick, grout filler	1,340	433
22	2	do	3½	do	1,410	497
23	2	do	3½	do	1,410	485
24	2	do	4	Repressed brick, grout filler	1,850	572
25	2	do	4	do	1,410	412
26	2	do	4	do	1,520	453
27	2	do	4	Wire cut lug brick, grout filler	1,940	504
28	2	do	4	do	1,250	364
29	3	do	3	do	800	245
30	3	do	3	do	1,810	538
31	3	do	3	do	1,170	306
32	3	do	4	do	1,910	319
33	3	do	3½	Vertical fiber brick, grout filler	1,590	362
34	4	do	3½	do	1,650	284
35	4	do	3½	do	2,040	344
36	4	do	3½	do	3,185	463
37	4	do	4	Repressed brick, grout filler	1,910	319
38	4	do	4	do	1,460	254
39	4	do	4	Wire cut lug brick, grout filler	2,420	421
40	4	do	4	do	2,110	304
41	4	do	4	do	2,480	403
42	5	do	3	do	2,040	340
43	5	do	3	do	2,740	444
44	6	do	4	Repressed brick, grout filler	3,510	400
45	6	do	4	do	3,060	353
46	6	do	4	do	4,210	427
47	6	do	4	Wire cut lug brick, tar-mastic filler	1,340	132
48	6	do	4	do	1,910	184
49	6	do	4	Wire cut lug brick, tar-mastic filler, screening cushion	1,655	154
50	6	do	4	Wire cut lug brick, tar filler, screening cushion	825	95
51	6	do	4	Wire cut lug brick, grout filler	2,810	269
52	6	do	4	do	2,610	305
53	6	do	4	do	2,480	306
54	6	do	4	do	1,850	351
55	7	do	3	do	4,840	485
56	7	do	3	do	2,925	358
57			3½	Vertical fiber brick, grout filler	700	574
58			3½	do	950	991
59			4	Repressed brick, grout filler	1,080	715
60			4	do	955	640
61			4	Wire cut lug brick, grout filler	955	623
62			4	do	1,020	679
63			4	do	1,280	829
64			4	do	900	608
65			4	do	1,120	754

TABLE 3.—*Compressive strength of concrete specimens.*

Specimen No.	Mix.	Ultimate total strength.	Unit strength.	Specimen No.	Mix.	Ultimate total strength.	Unit strength.
		Pounds.	*Lbs. per sq. in.*			*Pounds.*	*Lbs. per sq. in.*
1	1-3-6	62,220	2,200	9	1-1½-3	151,000	5,340
2	1-3-6	68,530	2,420	10	1-1½-3	149,000	5,270
3 [1]	1-3-6	72,000	2,540	11	1-1½-3	124,500	4,400
4 [2]	1-3-6	64,540	2,280	12	1-1½-3	137,000	4,850
5	1-3-6	82,700	2,920	13 [3]	1-3-6	86,050	3,442
6	1-3-6	56,200	1,990	14 [3]	1-3-6	81,520	3,430
7	1-3-6	58,570	2,070	15 [3]	1-1½-3	145,100	6,030
8	1-1½-3	128,000	4,530	16 [3]	1-1½-3	156,290	6,415

[1] Dry mix. [2] Wet mix. [3] Cubes cut from slab specimens.

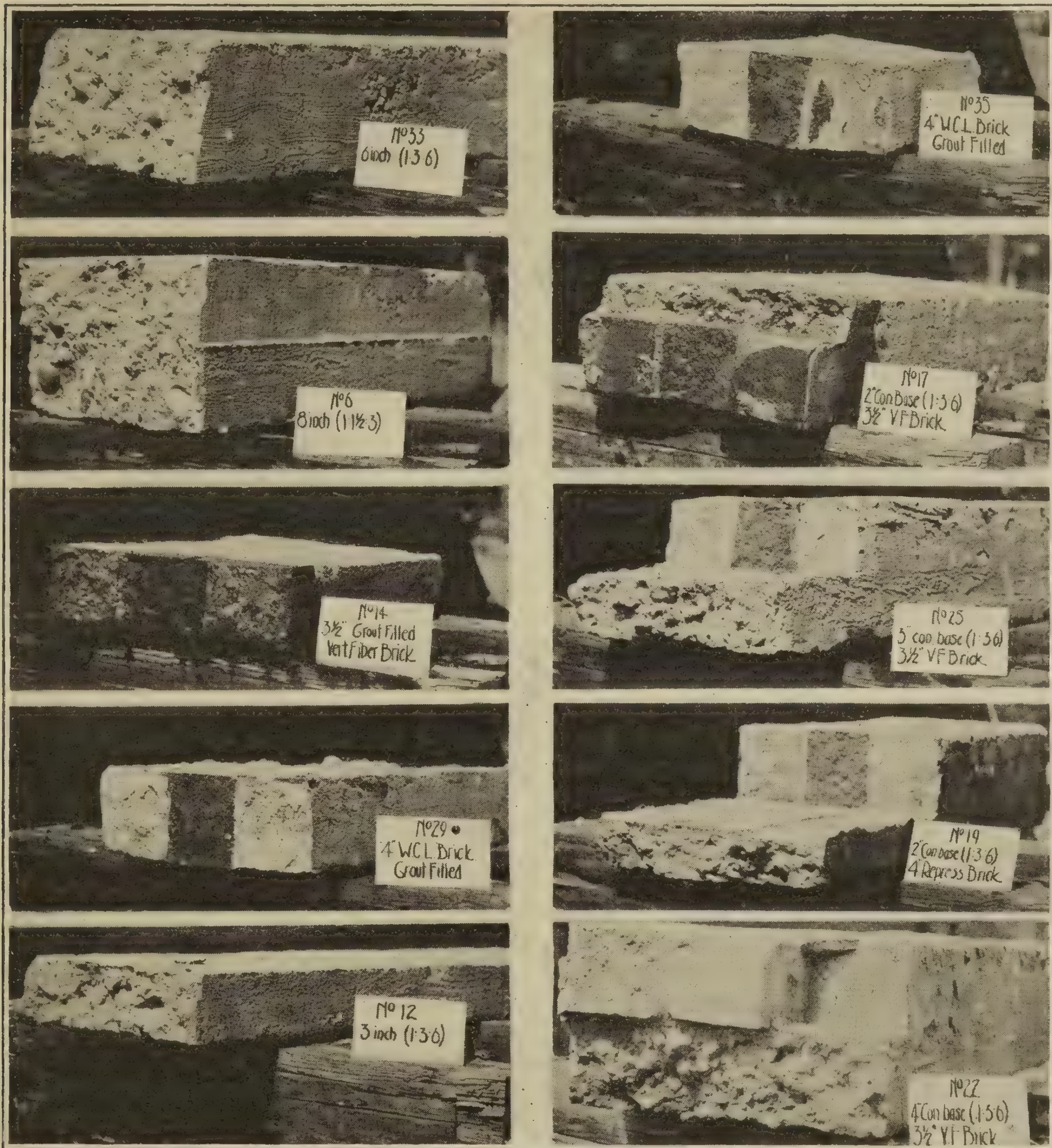


FIG. 9.—VIEWS SHOWING TYPICAL FRACTURES OF BEAMS.

by the breaking loads of 700 and 1,550 pounds for the 4 and 6 inch 1 : 3 : 6 concrete beams.

Table 3 gives the compressive strengths of specimens of concrete used in the slab construction. Nos. 1 to 7, inclusive, were 6 by 12 inch cylinders made from the 1 : 3 : 6 base concrete, and Nos. 8 to 12 were cylinders representing the 1 : 1½ : 3 concrete. Nos. 13 and 14 were cubes cut from slab No. 19 (1 : 3 : 6 concrete) after test, while Nos. 15 and 16 were cubes cut from slab No. 14 (1 : 1½ : 3 concrete) after test. The average strength of the cylinders is 2,346 pounds for the 1 : 3 : 6 and 4,879 pounds for the 1 : 1½ : 3 mix, while for the cubes it is 3,436 pounds for the 1 : 3 : 6 and 6,222 pounds for the 1 : 1½ : 3 mix. From these averages the compressive resistance of 1 : 1½ : 3 concrete is indicated to be approximately double that of the 1 : 3 : 6 mix. This relation is different from that shown by the moduli of rupture of the two mixes. Compared in that respect the 1 : 1½ : 3 mix was but 15 per cent better than the 1 : 3 : 6 mix.

RESULTS OF THE TESTS SUMMARIZED.

In summarizing the results of the tests a word should be said concerning the part played by the subgrade in resisting the blows delivered to the slabs. At the beginning of the tests, it is assumed that the slabs were in intimate contact with their subgrades. Therefore the first blows delivered to the slabs must have been resisted almost entirely by the subgrades, since the slab resistance could be developed only by deflection, and no deflection was possible without corresponding deformation of the subgrade. Once deformed, however, the subgrades failed to return to their initial elevations, while the slabs did spring back after each blow. The result was that it was necessary for the slabs to deflect more and more under each succeeding blow before the subgrade could be brought into play to assist in resisting the blow. With increasing deflection the stress set up in the slabs increased, and the resistance to the blow was offered to an increasing degree by the slabs and to a diminishing degree by the subgrades. The slabs failed when the stresses set up exceeded their strengths; but at the instant of failure the blow was probably resisted partly by the subgrades. It appears therefore that the slab resistances indicated by the tests were greater than they would have been if the centers of the slabs had been entirely without subgrade support. How closely the conditions of the tests in this respect conform to the conditions which exist in actual pavements it is impossible to determine, but it is believed that similar conditions do exist under many pavements.

For the test conditions of size, loading, and support of slabs, as previously described, the following indications are noted.

The resistances shown by 1: 1½: 3 concrete slabs, 7 feet square, are very consistent, increasing uniformly with increase in thickness. In slabs 6 inches and more in thickness only primary cracks developed, while 4-inch slabs shattered and punched out at the center. From this it would seem that plain concrete surfaces of 4-inch thickness are inadequate for heavy motor-truck traffic.

Comparison of the results of the concrete beam tests under static loads and the tests of concrete slabs under impact blows shows that the relation of resistance to thickness is not the same under the two conditions of loading. Beginning with the 4-inch slab which resisted 14,000 pounds equivalent static load, the resistance of the slabs, as measured by the equivalent static load at failure, increased 5,000 pounds with each inch of additional thickness, while the beam resistances varied as the squares of their depths. It must be remembered that the beam tests showed the resistance of the specimens alone, while slab results were conditioned by the bearing power of the subgrade. This might account in part for the difference observed; but according to theory the resistance of beams to impact does vary directly with the thickness. It would seem that the subgrade influence affected the resistance shown by the thinner slabs much more than that of the thicker.

The monolithic slabs in most cases showed less resistance than the 1:1½:3 concrete slabs of the same depth. Failure of the former seemed to result from the shearing of the brick top from the concrete base before full resistance of the monolith was developed. This allowed the specimens to develop at most only the sum of the resistances of the two parts. The monolithic sections tested as beams under static loads failed in the same way, but the resistance of the beams seemed to be slightly in excess of the sum of the top and bottom strengths, while the slab resistances compared favorably with the sum of the resistances of the two parts. This would indicate that higher shearing stresses are developed by impact than by equivalent static loads.

With possibly one exception (slab No. 106) the grouted-brick tops with sand-cement cushions on concrete bases showed less resistance than the monolithic sections.

Grout-filled brick tops with sand and screening cushions on concrete bases showed slightly greater resistances than would be expected from the bases alone.

Grouted-brick surfaces compared favorably with 1:1½:3 slabs of equal thickness, while grouted-brick beams showed resistances in excess of those offered by equal thicknesses of 1:1½:3 concrete.

As would be expected the beam strengths of the bases were not much increased by bitumen-filled brick tops.

With few exceptions other than the monolithic slabs, the indications were that failure occurred because of increase of the force of impact rather than by repetition of impacts of the same magnitude.

It was generally indicated that the resistance of the specimens increased with an increase in the bearing power of the subgrade as shown by the subgrade determinator.

There seemed to be no direct relation between the moisture content and the supporting value of the subgrade. It was found that the supporting value was least in the early spring after frost had left the ground and that it increased through the summer months. This increase of supporting value occurred notwithstanding attempts made to keep the subgrade under about one-half the slabs in a moist condition. During the summer it was noted that the supporting value was not much impaired by rains. Observations made at different periods, however, did show a higher moisture content in the subgrades surrounded by the ditches which were kept full of water than in the subgrades surrounded by dry ditches. In general, also the supporting value was less in the former.

The relation between the strength of 1:1½:3 and 1:3:6 concrete specimens, as shown by both the beam and slab tests was different from that shown by the compressive tests on cylinders and cubes. From the latter the resistance to compression for 1:3:6 was shown to be about 50 per cent of that for the 1:1½:3 mix, while the difference between the two mixes as indicated by beams and slabs does not exceed 15 to 20 per cent. It will be remembered also that the wear tests on pavement sections [1] failed to disclose any relation between compressive resistance and resistance to wear of the concretes made of the several different aggregates.

[1] Accelerated Wear Tests by the Bureau of Public Roads. Public Roads, June, 1921.

As a result of the studies with copper cylinders and the derivations from the space-time curves, and also as a result of the slab and beam tests, it appears that usable relations have been established between static loads and impacts such as were delivered in these tests.

PRACTICAL APPLICATION OF THE TEST RESULTS.

In all the impact experiments which have been conducted by the Bureau of Public Roads the end which has been constantly kept in view is the development of a rational method for the design of roads to withstand this destructive force. No investigation has been undertaken unless there was reason to believe it would contribute something of value toward this end. It has been necessary to do a great deal of work the results of which have had no immediate practical value. When it is considered, however, that at the outset of the tests there was not even an instrument with which to measure the effects of impact, it does not seem surprising that the earlier work could not be turned to instant practical use. The first stage of the tests, devoted to the search for a measuring instrument, resulted in the adoption of the copper-cylinder method. The second consisted in the use of the cylinders to measure the magnitude of the impact forces delivered by motor trucks moving at various speeds, with different conditions of tire, spring, load, and contact with the road. The third stage, which has been described in this series of articles, dealt with the development of an improved measuring instrument and the determination of the effect of impact on various pavements. Information of the character furnished by these series of tests is all that is needed for the solution of the problem of design, so far as the force of impact is concerned.

The range of conditions dealt with is not yet extensive enough and the data are not numerous enough to satisfy the requirements of practical design; but, in the main, what remains to be done is simply to fill in the details of the outline already laid down.

The manner in which the test results can be utilized is illustrated by the following example in which the conditions assumed correspond to the conditions of the tests.

Let us suppose a concrete pavement is to be designed to sustain safely the impact of a 5-ton truck loaded to capacity. It will be assumed that the character of the road surface and the condition of the tires of the vehicles which will use the road are such that the impact of the vehicles will be equivalent to that which would result by dropping the rear wheels from a height of one-fourth inch. Let it be assumed also that the pavement is to be designed to span small areas in which it will receive very little subgrade support, a condition similar to that which existed in the tests.

TABLE 4.—*Impact caused by different motor trucks.*

Rated capacity of truck	Load.	Load on one rear wheel.			Equivalent static load for different heights of fall.		
		Total.	Sprung.	Unsprung.	0	¼ inch.	1 inch.
Tons.	*Tons.*						
1½	1½	3,475	2,410	1,065	5,500	7,800	10,200
1½	1½	3,475	2,410	1,065	4,500	6,300	11.500
1½	2¼	4,240	3,175	1,065	4,700	10,000	16,000
1½	2¼	4,240	3,175	1,065	4,900	5,900	9,200
2	2	4,300	3,300	1,000	6,800	7,800	11,500
2	2	4,300	3,300	1,000	6,800	8,500	13,400
2	2	4,300	3,300	1,000	6,800	7,900	11,000
2	2	4,300	3,300	1,000	6,800	7,500	11,000
2	3	4,900	3,900	1,000	7,200	8,500	14,000
2	3	4,900	3,900	1,000	7,300	8,600	13,700
2	3	4,900	3,900	1,000	6,800	8,000	11,000
3–3½	2½	5,150	3,450	1,700	8,400	9,200	15,700
3–3½	2½	5,150	3,450	1,700	8,200	8,700	11,800
3–3½	2½	5,150	3,450	1,700	8,200	9,300	14,100
3–3½	2½	5,150	3,450	1,700	6,900	9,200	21,500
3–3½	2½	5,150	3,450	1,700	8,000	8,200	12,200
3–3½	2½	5,150	3,450	1,700	8,700	8,200	13,000
3–3½	4½	7,000	5,300	1,700	....	10,000	19,000
3–3½	4½	7,000	5,300	1,700	9,700	9,700	19,000
3–3½	4½	7,000	5,300	1,700	9,300	9,800	17,700
3–3½	4½	7,000	5,300	1,700	9,200	11,000	17,200
3–3½	4½	7,000	5,300	1,700	10,000	10,000	18,000
3–3½	4½	7,000	5,300	1,700	10,000	11,000	15,800
5	5	7,900	5,950	1,950	11,000	12,800	18,000
5	5	7,900	5,950	1,950	11,000	12,500	19,000
5	5	7,900	5,950	1,950	9,000	10,000	16,000
5	5	7,900	5,950	1,950	9,200	10,700	15,500
5	5	7,900	5,950	1,950	9,200	9,700	13,000
5	5	7,900	5,950	1,950	9,500	....	15,000
5	7½	10,600	8,650	1,950	12,200	15,300	26,000
5	7½	10,600	8,650	1,950	12,000	13,700	21,000
5	7½	10,600	8,650	1,950	11,500	12,500	18,500
5	7½	10,600	8,650	1,950	11,500	12,600	17,200
5	7½	10,600	8,650	1,950	11,000	11,200	16,800
5	7½	10,600	8,650	1,950	11,200	12,100	15,800

To meet these conditions the designer would refer first to the results of the measurement of motor truck impact. A brief summary of these results is given in Table 4. The table shows the impacts delivered by the rear wheels of trucks of various sizes, variously loaded, and dropped upon the road surface from three different heights. The average impact resulting from a one-fourth inch drop of the rear wheels of a 5-ton truck loaded with 5 tons, as shown, is equivalent to a static load of about 11,000 pounds.

Several corrections must be applied to this value before it can be used. In the first place the tabular values represent the impacts delivered by trucks equipped with new solid tires. The tests showed that the use of worn tires might increase the impact by from 15 to 60 per cent. Assuming that the use of badly worn tires will be prohibited by law let us apply a correction of 30 per cent which will increase the tabular average to 14,300 pounds equivalent static load.

Also since the tabular values were obtained by the use of one-half by one-half inch copper cylinders, they are less than the true impacts, and it will therefore be necessary to apply the correction indicated in the first article of this series. Finally, as insurance against overloaded trucks, and other conditions such as the use of nonskid chains which would increase the impact, let us double the estimated impact. The tabular values of impact increased by 30 per cent for tire condition and corrected to eliminate the effect of the copper cushion are shown in curves 2, 3, and 4 of figure 10. Curve 1 shows the total static load on one

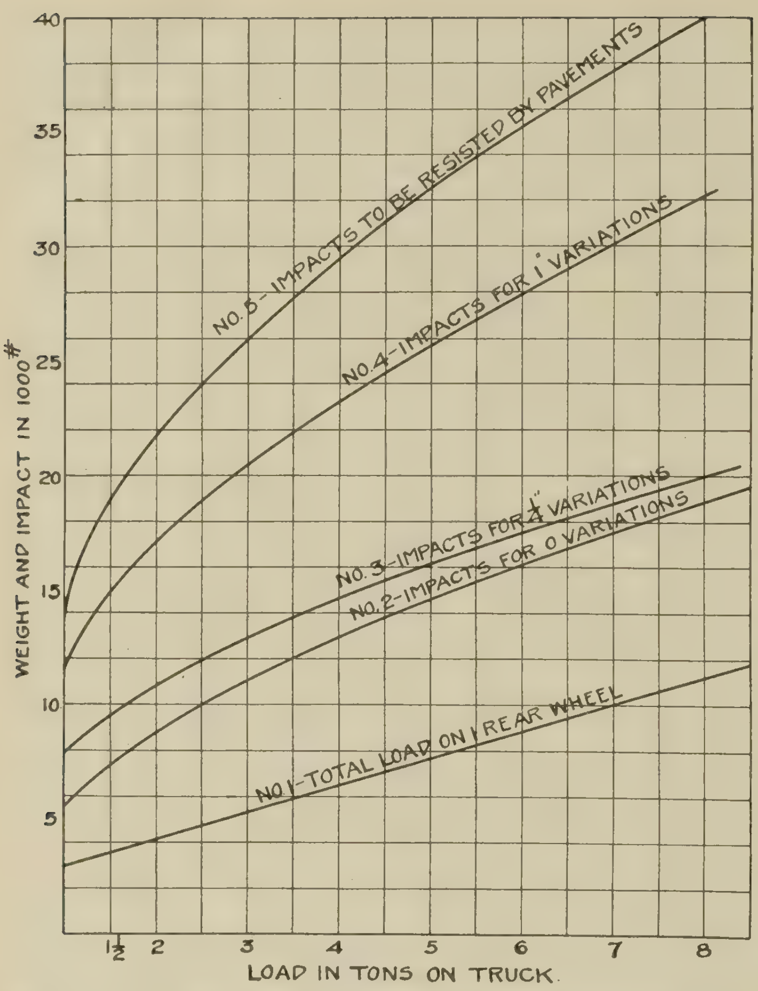


FIG. 10.—TOTAL WHEEL LOADS AND IMPACTS FOR TOTAL LOAD CARRIED ON TRUCK.

rear wheel and curve 5 shows double the values of the corrected impacts for the one-fourth-inch drop. In each case the impacts or loads are shown in relation to the load carried by the truck. Referring then to curve 5, we find that in designing a pavement for a 5-ton truck loaded to capacity, provision must be made for an equivalent static load of 32,500 pounds, which is slightly more than four times as great as the total load on one rear wheel of the truck as shown by curve 1.

Having thus determined the impact for which the surface is to be designed, the thickness required is indicated by the results of the slab tests reported in this article. For 1 : 1½ : 3 concrete slabs the average results of these tests are shown in figure 11, which gives the resistance of slabs of various thicknesses. Referring to this figure it is found that a 1 : 1½ : 3 concrete pavement to withstand the impact of 5-ton trucks loaded to capacity and operated under the assumed conditions must have a thickness of between 7½ and 8 inches.

Proceeding in a similar manner from other assumptions it can be shown that the thicknesses of 1 : 1½ : 3 concrete required for various sizes of trucks are as follows: For a 1½-ton load, 5 inches; for a 2-ton load, 5.5 inches; for a 3-ton load, 6.4 inches; for 4 tons, 7.1 inches; for 5 tons, 7.7 inches and for a 7½-ton load, 8.9 inches.

These thicknesses are given merely as the results of an example which is cited to illustrate a method of design. They are not to be considered as the proper thicknesses of actual pavements to accommodate vehicles of the several capacities; nor is the curve in figure 11 to be understood to represent anything other than the average relation of resistance to thickness in the particular tests which have been described.

One of the reasons why the results can not be generally applied is that they relate only to the special subgrade conditions which existed at the Arlington Experimental Farm. There is no assurance that the resistances of the slabs tested would not have been widely different if they had been laid on different subgrades. On the contrary, there is every reason to believe that they would have been different.

Another obvious reason is that the slab resistances used were derived from tests in which the impact was delivered only to the centers of the 7-foot slabs, and it is known that this is the most favorable condition. Less resistance would have been offered to impact applied at their edges, and still less to blows delivered at their corners.

These reasons indicate the need for further research. In respect to the subgrade the first need is to devise a method by which the supporting value may be measured, the next is to find out how and to what extent it is affected by moisture and other natural conditions. These problems solved, it will still be necessary to study the changes which affect the shape of the subgrade, such changes, for example, as are caused by frost and the pounding of traffic, for with rigid surfaces the support offered by the subgrade depends not only on its supporting value but also upon the nature of its contact with the surface. And this study will necessarily include the behavior of the surface as well as the subgrade, for the desired contact may be lost by the movement of the road slab itself. The bureau's tests have

[Continued on page 27.]

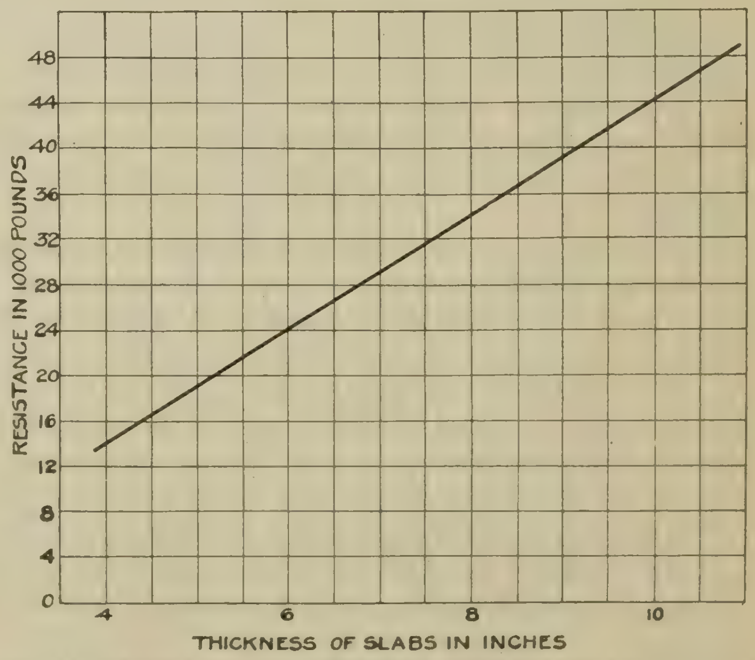


FIG. 11.—RESISTANCE OF DIFFERENT THICKNESSES OF 1 : 1 1-2 : 3 CONCRETE SLABS.

"ROLLED-BASE" BRICK ROADS IN OHIO

By A. T. GOLDBECK, Chief of Division of Tests, and F. H. JACKSON, Senior Assistant Testing Engineer, Bureau of Public Roads.

AN inspection of a number of brick roads of the so-called "rolled-base" type was conducted recently by the authors for the purpose of obtaining some information regarding their behavior under various traffic and subsoil conditions. A detailed description of these roads, together with comments regarding methods of construction, soil drainage, and traffic conditions as well as conclusions drawn as the result of this inspection follow.

Pavements of the "rolled-base" type include those in which the base consists of one or more courses of crushed stone, gravel, or slag, rolled and thoroughly bound with screenings. Upon this rolled base is then spread a 1 to 2 inch course of sand, stone, or slag screenings upon which the brick are bedded. The joints in the brick are filled with either cement grout, tar, tar mastic, or asphalt, one of the soft fillers ordinarily being preferred for reasons pointed out below. This type of construction has found considerable favor in certain sections of Ohio and near-by States as well as in the South, principally because of the opportunity it affords for the utilization of local materials in the base course in place of a more expensive concrete base.

This inspection was confined to the State of Ohio. In addition to the usual information regarding the materials of construction, thickness of base, character of traffic, age, etc., a study was made of any indications of foundation failure either past or present as shown by depressions or waves in the surface or by patches. Samples of subgrade material were taken and submitted to the laboratory for test, and the results of a preliminary examination of these soils are given in the table.

ROADS IN SOUTHERN OHIO CONSTRUCTED ON LIMESTONE BASE.

Brick roads of the "rolled-base" type in this section of the State are constructed very largely with the local limestone gravel as base material, the prevailing thickness of base being 6 inches. This gravel is of excellent quality and has proved very satisfactory as a surfacing material under light traffic conditions. The Columbus-Chillicothe road is paved with a grouted surface of repressed brick laid on a 6-inch compacted gravel base. The sections examined were from 6 to 8 years old and were in general in very satisfactory condition. Some side breaks probably caused by settlement were noted. These had been repaired at the time of inspection. Figure 1 shows the excellent condition of the grouted surface. The prevailing soil type is a gravelly loam which drains easily. Two samples were taken, one of which (No. 137) represents the average soil type, and the other (No. 138) the character of soil under one of

FIG. 1.—GROUT FILLED BRICK PAVEMENT ON GRAVEL BASE, COLUMBUS-CHILLICOTHE ROAD.

the few places where evidences of foundation failure were observed. This failure took the form of a center settlement several square yards in extent which had been repaired with bituminous material at the time of the inspection. It will be noted that there is somewhat more clay in the soil under the failure. The road is said to have received exceptionally heavy traffic during the war. At present the road is used by a heavy traffic of automobiles with some heavy trucking.

PHYSICAL TESTS OF SUBGRADE SOILS.[1]

Lab. No.	County.	Mechanical analysis.						Moisture equivalent.[2]	Water capacity.[3]	Capillarity.[4]
		10–20	20–50	50–100	100–200	Silt.	Clay.			
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
137	Ross	17	24	8	7	24	20	12	32	24
138	do	6	15	8	6	35	30	17	38	25
142	Stark	1	9	7	4	40	39	20	43	27
152	Muskingum	3	6	10	9	40	32	20	37	25
153	do	8	9	8	8	24	44	26	42	29
154	do	0	3	3	4	64	26	26	50	33
155	Guernsey	0	1	3	3	29	64	28	63	39
159	Trumbull	0	3	3	2	21	71	27	42	29
160	Cuyahoga	3	7	6	5	25	54	23	45	29

[1] See "Tests for Subgrade Soils," by A. T. Goldbeck and F. R. Jackson, "Public Roads," July, 1921.
[2] Percentage of water, based on dry weight of soil, which is retained against a centrifugal force approximately 750 times the force of gravity.
[3] Maximum percentage of water, based on dry weight of soil, which can be retained by the soil under any circumstances.
[4] Percentage of water, based on dry weight of soil, lifted by capillarity under a given set of conditions.

The road south of Chillicothe is almost identical with the road just described in point of construction and soil conditions with the exception that a tar-mastic filler was used and the 6-inch gravel base was constructed on an old gravel road. It has been under traffic about six years and is subjected to moderately heavy truck traffic. The surface is in excellent condition, as shown in figure 2, the only defect noticeable being the tendency of the mastic filler to pull out of the joints. No evidences of foundation failure were observed. Soil sample No. 139 was taken from the shoulder on this road.

FIG. 3.—REPRESENTATIVE SECTION OF THE NATIONAL ROAD, A TAR-MASTIC FILLED BRICK ROAD ON A CRUSHED SANDSTONE BASE.

THE NATIONAL ROAD, A HEAVY TRAFFIC HIGHWAY.

A considerable mileage of the highway known as the National Road between Wheeling and Zanesville is paved with brick on rolled-stone base. The heavy through traffic which uses the road and the unfavorable soil conditions which are frequently encountered make a study of its present condition highly desirable.

The portion of the road lying in Muskingum County and east of Zanesville (fig. 3) was constructed in 1918 and due to war conditions every effort was made to complete it in the shortest possible time. The road is in two sections, about 13 miles long and is constructed for the most part on a base consisting of the soft local sandstone, showing a percentage of wear in the neighborhood of 20 by the standard Deval abrasion test. The nominal thickness of base is 8 inches, 3½-inch brick were used, and the filler was a tar mastic. A detailed inspection at several points along the road failed to show any serious foundation failures. In one place just east of Zanesville the highway was constructed over an 18-foot fill. Some movement in this fill has caused the road to settle very slightly resulting in a somewhat uneven surface on the side of the road where the fill is deepest. The condition of the road at this place illustrates very forcibly the value of using a flexible slab for wearing surface under conditions similar to those just described. Had the brick surface over this fill been grouted as was the former practice on roads of this type the slab would undoubtedly have cracked under the impact of traffic due to the yielding support and the section would probably have failed entirely by this time. As it is, the slight settlement is the only evidence that anything unusual has taken place.

FIG. 2.—BRICK ROAD ON GRAVEL BASE, TAR-MASTIC FILLER.

Three samples of soil were secured, one (No. 152) from the 18-foot fill, just described, one (No. 153) which is supposed to represent the poorest soil condition along the road, and one (No. 154) which was taken to represent an average soil condition. The physical properties of all these soils are given in the table. The analyses of these soils illustrate the variation in the character of the soil along this road.

Sections of the National Road in Guernsey County were also inspected, as well as three short sections leading north from Cambridge. Most of these roads are grouted and some have been down as long as nine years. Numerous longitudinal cracks characterize the grouted sections, especially in those portions which have been under traffic for a number of years. Some evidences of foundation failure were also observed. Failures of this type usually took the form of settlement along the edges of the road. In certain cases concrete curbs had risen as much as 4 inches, probably as the result of frost action. The general soil conditions about Cambridge are about the same as in Muskingum County. A sample (No. 155) taken just south of Cambridge illustrates one of the worst soils in this section of the State. Heavy clay soils such as the one represented by this sample are extremely difficult to drain especially when the highway lies on a low level where the surrounding natural drainage conditions are poor.

POORLY DRAINED ROADS IN NORTHEASTERN OHIO.

Inter-County Highway No. 70–C, in Stark County, leading toward Canal Dover is 6 years old. The tar-filled brick surface was constructed on an old gravel road using a slag base about 6 inches thick. The character of the soil is illustrated by sample No. 142. At the time of inspection the subgrade was very hard, compact, and impermeable. Water standing in the ditches at several places indicated poor natural drainage. A tendency for brick to chip at the edges, due to failure of the tar filler to protect them, was noted. Some settlement has occurred next to the curbs, but it has been fairly uniform and no actual punching through of the surface was observed in any place. This settlement along the edges may possibly result from the fact that the old road was only from 8 to 12 feet wide. Lack of uniform compaction of the new base along the edges may therefore account for the side settlement.

Portions of Inter-County Highway No. 73 were next examined. One section of this road was constructed on a 4-inch concrete base with 2-inch sand cushion and grout filler. The other was built on a 6-inch rolled-slag base, using grout filler. Both of these roads are subjected to exactly the same traffic and both have identical drainage. The section laid on the concrete base shows considerable longitudinal cracking as well as some local failures which are due either to poor grouting or possibly to foundation failure. The section laid on slag base showed considerable settlement at the edges, and in general, a somewhat more uneven surface than that laid on the concrete base. A typical foundation failure on the rolled-base section is shown in figure 4. The country is flat instead of rolling and it is therefore difficult to obtain natural drainage of water away from the roadway. Due to this condition water stands in the ditches a large part of the time, and this undoubtedly helps to keep the subgrade saturated. In spite of these very poor drainage conditions, however, the road is still in fairly good condition, the only evidences of foundation failure of any moment being those previously referred to.

FIG. 4.—GROUTED BRICK ON 6-INCH SLAG BASE STARK COUNTY, OHIO.

FIG. 5.—GROUTED BRICK ROAD ON SLAG BASE, MAHONING COUNTY, OHIO.

Another illustration of grouted brick on rolled-slag base was observed on the road from Akron to Youngstown. This section was built about 6 years ago and has an 8-inch base. Many longitudinal cracks were observed and some evidences of foundation failure at the edges. A typical view of one of these sections is shown in figure 5.

In spite of cracks and local failures this road is, in general, in very good condition.

GENERAL COMMENTS.

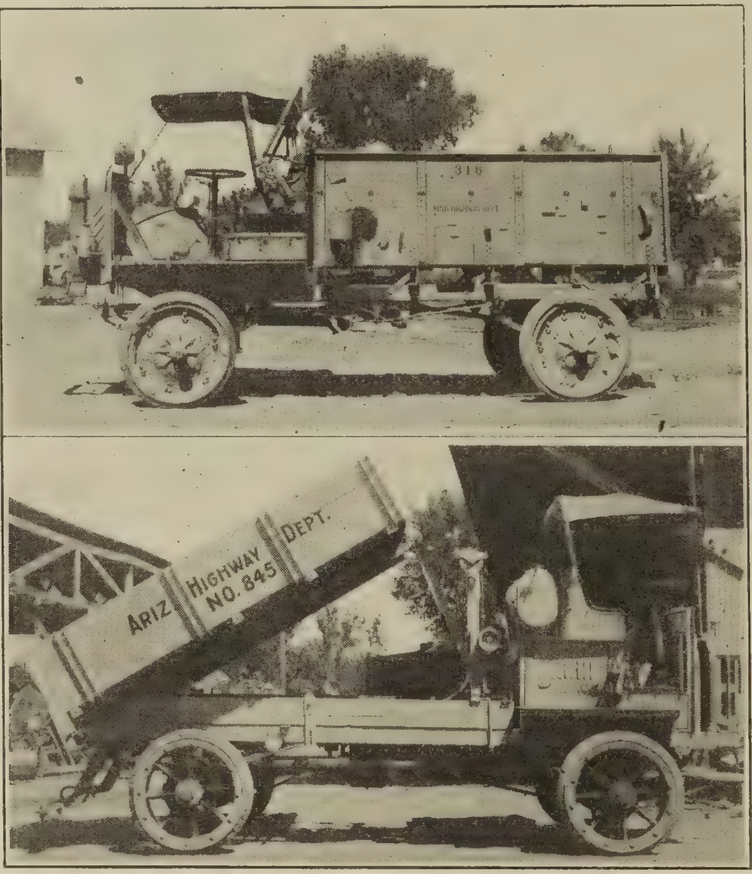
The results of this inspection supplemented by information obtained from various county engineers and others interested in the "rolled-base" type of construction would indicate that it may be used successfully even under rather unfavorable soil and drainage conditions. Of course, like every other pavement type, best results have been secured when these conditions make possible a firm, stable foundation at all seasons of the year, such as may be obtained with a sandy soil in a gently rolling country where satisfactory natural drainage may be secured. Under these conditions the "rolled-base" type is apparently giving satisfactory service even under heavy traffic provided a flexible wearing surface is secured by the use of a bituminous filler. This statement would seem to be justified by the behavior of the roads in southern Ohio, especially in the vicinity of Camp Sherman, Ohio, where they carried very heavy traffic during the war. The 6-inch compacted gravel or stone bases of these roads seem to be adequate.

The National Road in Muskingum County is an example of the "rolled-base" type under rather unfa-

[Continued on page 28.]

ARMY MATERIALS INGENIOUSLY USED BY STATES FOR ROAD CONSTRUCTION

ONE hundred and forty million dollars is the estimated value of the surplus war materials, supplies, and equipment transferred to the 48 States by the Department of Agriculture up to November 1. The only reservation made by the Government in turning over these valuable supplies under the Wadsworth-Kahn Act is that they shall be used only in the construction and maintenance of roads.



TOP—ORDNANCE TRUCK AS RECEIVED FROM THE GOVERNMENT. BOTTOM—THE SAME BODY AS CONVERTED BY ARIZONA FOR ROAD WORK.

Over 27,000 motor vehicles, both trucks and automobiles, and nearly $12,000,000 worth of spare parts for them have been included in the transfer, and in addition a great variety of machinery and supplies has been distributed, the mere listing of which requires ten closely typewritten pages.

Although all of the material was purchased originally to meet the needs of the Army in time of war, a large part of it can be utilized for highway construction without any alteration. In this class are hand tools of all kinds, such as picks, shovels, axes, adzes, chisels, etc., and machinery and equipment commonly used in road construction such as cranes, derricks, steam shovels, wheelbarrows, jacks, and other items too numerous to mention.

In addition to such material as this, however, there were many other items of material declared surplus by the War Department which were not suitable for road-construction purposes in their existing form but which the States have found ways to alter and utilize to excellent advantage. The story of some of the ingenious and economical uses of this material, designed primarily for warlike purposes, forms an interesting chapter in the record of the tremendous salvaging operation which has been carried on under the Wadsworth-Kahn Act.

ARMY TRUCKS CONVERTED BY CHANGING BODIES.

The motor trucks, of which over 23,000 have been transferred, are perhaps the most valuable equipment which the States have received. As they were received from the Army they were generally not suitable for road construction purposes, on account of the shape and size of their bodies, which were designed especially for Army use. But the States have altered these bodies, in some cases in their own shops built for the purpose, thereby converting the trucks to a number of special uses.

The majority of the trucks have been altered by substituting dump bodies and hoisting devices for the cargo and ammunition bodies with which they were equipped when received. In some cases new bodies have been built outright; in others the Army bodies have been converted. Idaho, for example, has converted the steel ammunition bodies into hopper bodies by installing false bottoms sloping from front and back to a pair of drop doors for bottom dumping which are controlled from the driver's seat. Maine has removed the cargo body from the chassis and by pivoting it near the rear end and adding a hoisting device has made the Army body into a dump body. The same State and also Vermont have altered the Army bodies by arranging the sides so that they can be dropped or raised, permitting the load to be dumped from the side of the truck.

Arizona sized up the trucks equipped with steel ordnance bodies and decided that for road work they were too high and not wide enough. To make them suitable they cut the bottoms in half from front to back, and then used the sides for a new bottom and the two halves of the bottom for the new sides, thus making the body about twice as wide and half as high. The change makes it easier to shovel into the truck when necessary and also permits the hauling of more bulky material. In addition, the trucks have been equipped with hand hoists and offset bars on the rear end in order to pull road scrapers and drags. As shown in two of the illustrations, the original body is hardly recognizable in the converted form.

In addition to using the trucks for hauling road materials many of them have also been converted to other uses. Army ambulances have needed few alterations to make them admirable survey cars. A few changes also convert these vehicles into trucks for the transportation of convicts to and from their work on the roads. Nearly all the States in which there is any snow problem at all have utilized a portion of their truck allotment in winter to push snow plows; and one of the other common conversions is that which results in a very serviceable sprinkler truck.

AN ARMY TRUCK CONVERTED TO SPRAY WHITEWASH ON POLES IN NEW JERSEY.

Odd but ingenious use has been made by New Jersey of a Mack truck originally intended as a water sprinkler and equipped with a centrifugal pump which was mounted beneath the tank and driven by the propeller shaft. This was changed to a machine for spraying whitewash on poles along the State highways. The sprinkler heads at the rear were disconnected and two other connections were made from the outlet of the pump—one extending forward, the other to the rear. The forward connection was carried to pipes at each side which rise to the top of the cab and are there connected to garage car-washing swivels. The other connection enters the tank through the filling cap in the bottom. Inside the tank on this connection was placed an ell with a short nipple pointing forward. This connection was made for the purpose of agitating the whitewash mixture by pumping a part of the mixture back into the tank, and in order to increase the agitation the nipple at the end of the connection was flattened. The spraying mixture is pumped through the forward connection, and the garage swivels lengthened to 10 feet with 25 feet of hose attached permit traffic to pass while the truck is at work.

A WAREHOUSE FOR WAR MATERIALS IN ARIZONA, BUILT WITH GOVERNMENT MATERIAL. NOTE THE TRUCK SEAT TOPS USED AS AWNINGS.

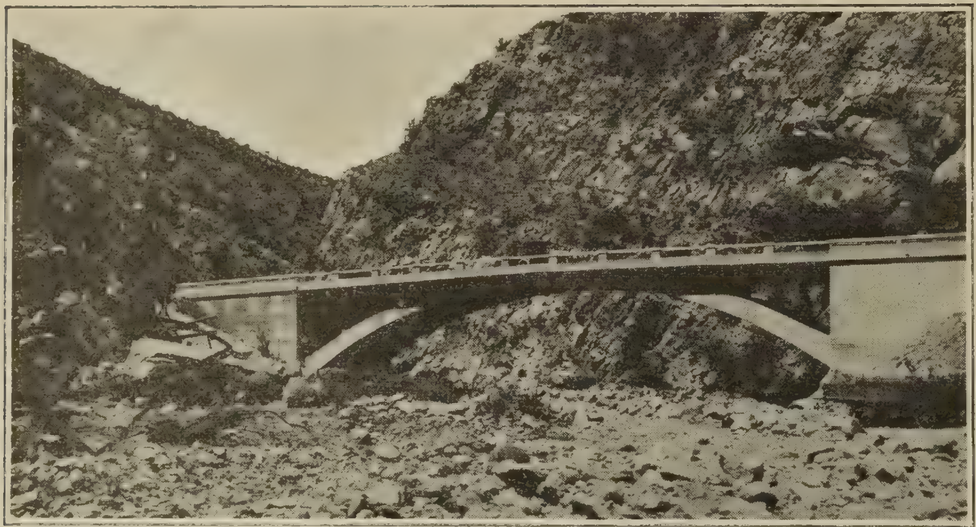
WAREHOUSE AS WELL AS CONTENTS FROM GOVERNMENT.

Arizona has built a warehouse for the storage of its transferred equipment out of material also received from the Government. The sides of the 50 by 100 foot building are covered with corrugated iron, of which some 5,000 sheets have been distributed by the bureau. The very efficient awnings over the office windows which are shown in the view of the building are made of extra tops for truck drivers' seats.

In other States the problem of providing temporary storage space for transferred war material has been solved by the use of the canvas airplane hangars, several hudreds of which have been distributed.

BOMB-PROOF SHELTERS SERVE VARIETY OF USES.

Among the items which appear in the list of distributed material are two described as "Shelters, elephant and trench." It would be difficult to imagine anything less likely to be of value in road construction than these heavy, semicylindrical bombproof iron shelters which were designed for the one purpose of protecting our soldiers from the shells of the enemy. Yet thousands of these shelters have been distributed by the Department of Agriculture and put into service in a number of useful ways by the States. The most common use ofthem has been as storehouses and magazines for the storage of Government TNT and powder. It is probable this use was suggested by the original purpose of the shelters. Colorado has departed a little further from the original purpose, and though it uses them for protective purposes, the protection sought is against



QUEEN CREEK BRIDGE, ARIZONA, A FEDERAL-AID PROJECT, ON WHICH THE HAND RAIL IS MADE OF SURPLUS WAR PIPE PREVIOUSLY USED TO CARRY COMPRESSED AIR TO JACK HAMMERS.

the storms of the mountain passes in which they have been erected. Arizona has gone farthest afield in its ingenious use of them as culverts. In the large desert areas of the State it seldom rains, but the rain that does fall is likely to come in cloud-bursts which flood the desert and frequently wipe out the roads which cross the wide, shallow drainage channels unless they are amply protected by culverts of liberal size. It is as a means of protection against these floods that the State is transforming the bomb-proof shelters into culverts. They are built on concrete foundations where sand and gravel are accessible, or on redwood in the absence of these materials. The rainfall is so infrequent and the desert soil is so porous that excess moisture is quickly absorbed, and it is thought that the shelters, well painted, even if not galvanized, will have a length of life which will amply justify the cost of installation.

ALTERATION OF ARTILLERY HARNESS REPAID BY THREE MONTHS' USE.

Although no material has been sent to any State except upon the request of the State authorities, some question has been raised as to the value of certain materials for road work. One of the items questioned was the artillery harness, over 16,000 sets of which have been distributed. For Army use this was made as breast harness, which differs from the hame harness commonly used. In its original form, therefore, it was valueless, but that it was far from valueless when properly altered has been shown by the experience of a number of the States typified by the following report from Arizona. The State engineer says: "The breast harness received by the State of Arizona from the Government has been changed to hame harness by our local saddleries at a cost of $10 per set. Thus changed each set is easily worth $40 to the State. We are now hiring stock without harness at a decreased price of $5 per team, so that the rent saved in three months pays all the expenses of freight on the harness and necessary alterations."

TNT MAKES PLACE FOR ITSELF.

Until the transfer of war materials placed it in the hands of the State road builders TNT had never been used except by the Army. In the popular mind it was regarded as the most dangerous of explosives—far more dangerous than dynamite—and entirely too dangerous for use except in time of war. This erroneous impression was dispelled by scientific investigation and the States were induced to try some of the explosive in their work. A single trial has been sufficient to convert the most suspicious blaster, and it is now generally preferred to dynamite by those who have used it. Nearly 20,000,000 pounds have been transferred to the States and the Bureau of Public Roads has used over 7,000,000 pounds in connection with its own work on the national forest roads.

NEARLY 150 MILES OF PIPE SALVAGED.

Nearly 150 miles of pipe, of assorted types and sizes has been saved from useless deterioration and put to work by the several States. It is safe to say that it has been used in nearly all the ways pipe can be used. A great deal of it has been used to carry water to concrete mixers. Nebraska has used the 2-inch size for heating coils to warm the garages which house the war trucks; and a great deal of the same size has been used to form the hand-rails of bridges and culverts. A most interesting example of the manner in which the transferred material is helping the States to solve their problems is that of the Queen Creek Bridge on the Superior-Miami Highway, Arizona. The handrail of this bridge is made of 4-inch wrought-iron pipe received from the Government. Before it went into the bridge rail, however, it was used to carry compressed air from ex-Government air compressors to the jack hammers used in the excavation of the bridge foundations. Incidentally, in addition to the assistance which the State has received by the transfer of Government material which has been used in this bridge, the State has also received financial aid under the Federal-aid act.

SECTIONAL BRIDGES USED IN NATIONAL FORESTS.

The building of bridges in the national forests has been materially aided by the special bridge material received from the War Department. This material, of which about 75 carloads have been received, consists of parts for I-beam bridges, fabricated truss sections, and a quantity of unfabricated steel shapes.

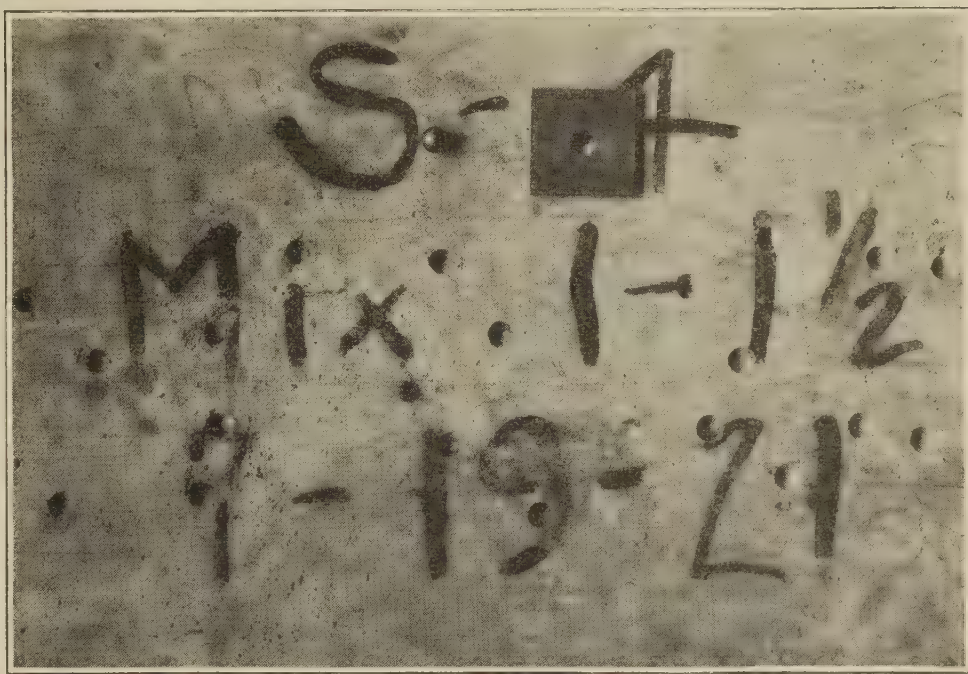
Most interesting of this material are the sectional bridges, one of which is illustrated on the cover page. Two types of sections are provided, one type 17 feet

[Continued on page 28.]

BALL TEST APPLIED TO CONCRETE

By W. K. HATT, Director Advisory Committee on Highway Research, Division of Engineering, National Research Council.

THE load required to press a steel ball into the surface of a material is a good index of the general strength qualities of some materials. In the form of the Brinell test it is used for steel, and it also applies to wood. In recent experiments, made by the Purdue University laboratory for testing materials in cooperation with the Bureau of Public Roads, the test has been applied to the surface of 1 : 2 mortar slabs, and the results seem to indicate that it will be valuable as applied to mortar and concrete as well as to other materials.



APPARATUS AND SLAB AFTER TEST.

The apparatus, which is very simple, consists of a steel ball one-half inch in diameter and a steel plate 2 inches square by one-fourth inch in thickness with a hole one-half inch in diameter through its center. The plate, with the ball in the hole, is placed on the surface of the mortar slab and a load is applied to the projecting ball (fig. 1) through the moving head of a testing machine or a jack or by any other convenient means.

When the load is applied the ball sinks into the mortar or concrete, the resistance gradually increasing with the penetration, until the ball has been driven into the surface to a depth equal to one-half its diameter, when the head of the testing machine or the jack bears on the plate and a sudden increase in resistance is indicated. This event marks the completion of the test and the load when it occurs indicates the strength of the surface of the mortar. The record of a test is shown in figure 2, and a photograph of a tested surface in figure 3. When the test is applied to concrete the ball should rest on mortar and not on a piece of aggregate.

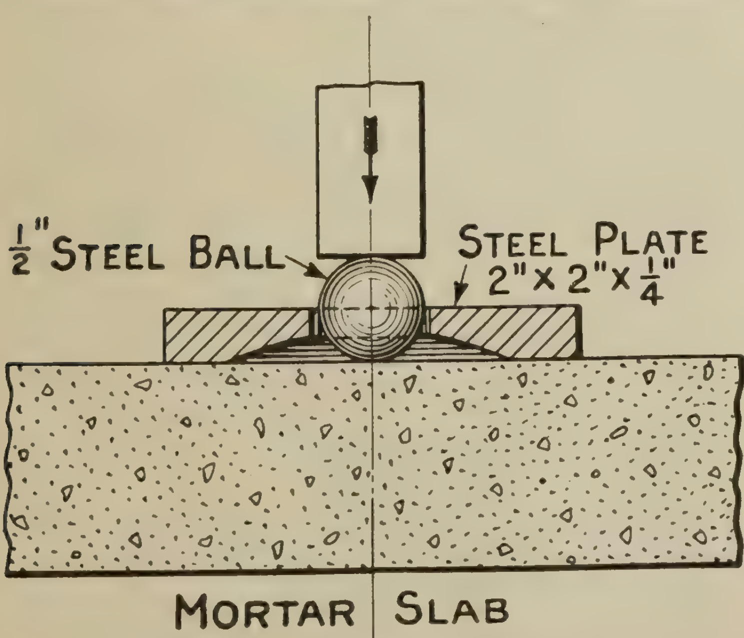


FIG. 1.—APPARATUS REQUIRED FOR THE BALL TEST.

The test is being used in the Purdue laboratory to study the effect of wheel loads on the surface of mortar slabs. A 34-inch truck wheel with a 4-inch solid tire is pressed on the slab with a load of 1,000 pounds. The wheel is then moved to a different place on the slab and pressed on with an increased load. In a similar manner several increments are added to the load and each time the wheel is moved to a different part of the surface. The ball test is applied to the parts of the surface subjected to each load and the effect of the increase is indicated by the loads required to force the ball into the surface. The test has been applied thus far to mortar slabs 7 and 28 days old with similar results. In each case the load required to force the ball into the slab decreases with increase in the load applied by wheel.

The correct interpretation of the results of the tests has not been determined; and before it can be standardized and applied for practical purposes it will be necessary to ascertain the effect of moisture, aggregate, and speed of test. It seems possible, however, that the test may be useful in a number of different ways.

The simplicity of the apparatus required suggests that it might be used as a field test to indicate when concrete in roads or structures has reached a satisfactory stage of curing so that traffic may be permitted or forms removed. The test might be applied to concrete roads for this purpose by employing a hydraulic

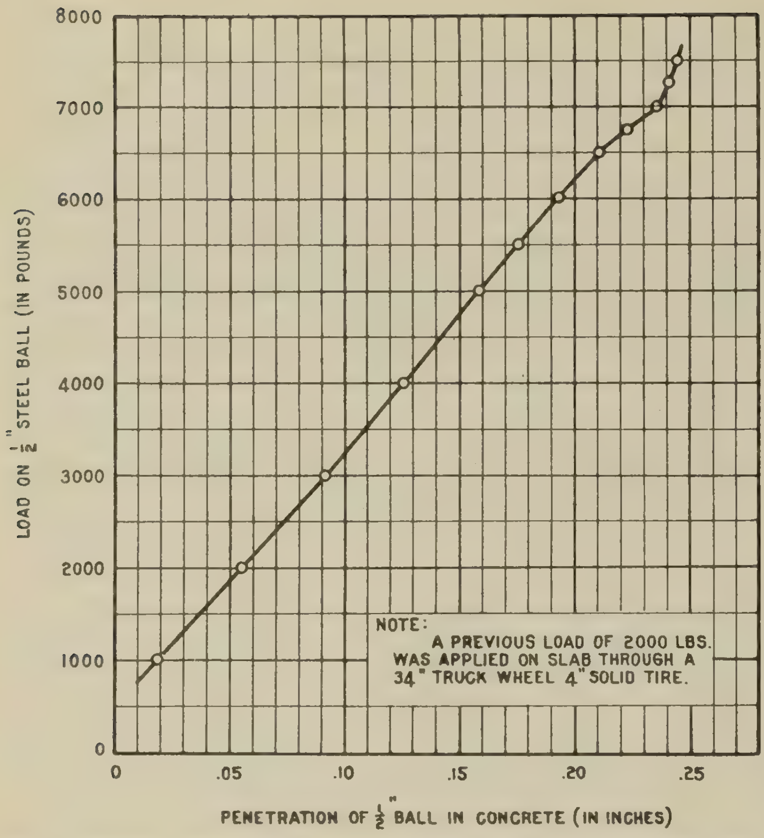


FIG. 2.—CURVE SHOWING LOADS APPLIED AND CORRESPONDING PENETRATIONS IN A BALL TEST, INDICATING BY THE SHARP BREAK THE POINT AT WHICH THE BALL PENETRATED TO ONE-HALF ITS DIAMETER.

jack and using the weight of a truck to supply a reaction to the jack.

Its use may also throw some light on the question of the action of long-continued traffic on a concrete road. It will be recalled that the report of the Bureau of Public Roads on highway construction in California showed that specimens taken from the roads of longer service were weaker in compression than specimens taken from roads of more recent construction. This showing, of course, might be explained by the fact that the more recent roads were built of a better concrete than the earlier roads. But this same suggestion of fatigue of concrete under service has been raised by some of the highway engineers in Maryland. Of course, in applying the ball test to the surface of concrete roads the effect of possible differences in the moisture content of the surface should be considered.

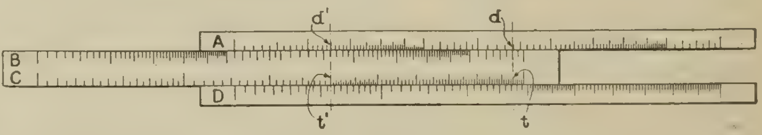
The property of fatigue of concrete under many loadings is being studied by direct laboratory tests conducted by Mr. Clifford Older, of the Illinois State Highway Commission; Dean A. N. Johnson, of the University of Maryland; and by the Purdue laboratory for testing materials. Mr. Older is applying repeated loads by the passage of an automobile wheel over the ends of projecting cantilever beams. Dean Johnson is bending a pair of beams by means of an eccentric cam placed between them. At the Purdue laboratory a concrete beam is bent back and forth, bringing about a reversal of stresses through the medium of a bracket attached to one end. Loads are applied alternately to the opposite ends of this bracket. Results obtained so far show that concrete will rupture under a repeated load that is less than the once-applied load required to break it. The same extension is reached in each case. A beam of 1:2 mortar, 28 days old, subjected to reversals of load at the rate of 10 per minute, cracked after 112,400 reversals and broke at 144,825 reversals of a 70-pound load. A similar beam broke under a once-applied load of 140 pounds.

SIMPLE SLIDE RULE SOLUTION OF VERTICAL CURVE FORMULA

By R. E. ROYALL, Highway Engineer, Bureau of Public Roads.

In calculating vertical curves most engineers use the formula $d' = \frac{dt'^2}{t^2}$ in which d' is the offset of any point, d the middle ordinate, t the length of the tangent, and t' the distance from the beginning or end of curve to the point at which the offset is desired. The maximum ordinate at the center of the curve is first determined, and then the offsets from the tangent are calculated by the formula.

Solved by ordinary slide rule methods the formula calls for two settings of the slide for each offset. The



method described below gives all offsets for any one curve with one setting of the slide and thereby saves considerable labor and time. Set the runner on d on scale A and under it set t on scale C, move the runner to the various values of t' on scale C, and in each case read the corresponding value of d' on scale A. In some cases the value of t' can not be reached on scale C, in which case the usual shift of the slide is made.

For example, suppose a 190-foot curve is desired to connect two grades of plus 4.30 and minus 1.55 per cent, respectively. The maximum offset is found to be 1.39 feet. Under 1.39 on A set 95 on C. Suppose the offsets at 85, 30, and 20 feet from the end of the curve are desired. Over 85 and 30 on C read 1.110 and 0.139 on A, then shift the slide and over 20 read 0.0615

There is no trouble in locating the decimal point if scale A is watched. The middle ordinate contains one unit, and at 80.6 feet the offset changes to tenths and at 25.5 to hundredths. To see this clearly it is necessary to set the slide rule for the above example.

The above offsets were found with a slide rule and are correct to three places except for an error of 0.006 in the first one. With careful settings the results should be obtained with an error of not more than 1 in the hundredth place.

WEST VIRGINIA GIRL WINS FOUR YEARS' UNIVERSITY SCHOLARSHIP

MISS GARLAND JOHNSON, Bridgeport, W. Va., was awarded a four-year university scholarship offered for the best essay written by high-school pupils during the 1921 "Good Roads and Highway Transport" national essay contest conducted by the Highway and Highway Transport Education Committee, Washington, D. C.

The scholarship, which has a value of not less than $4,000, is given by H. S. Firestone, a member of the committee. This is the second scholarship of its kind to be given by Mr. Firestone. A third contest for a similar prize will be announced early in 1922.

National judges were Dean A. N. Johnson, department of engineering, University of Maryland; Harford Powel, editor of Collier's Weekly; and C. H. Huston, Assistant Secretary, United States Department of Commerce. The judges read 52 essays, the best from each State and Territory.

Miss Johnson's essay follows:

"This morning the clank of chains and tramp of horses' hoofs called me to the window, where the road scraper was smoothing the highway before the house. This afternoon a sudden rainstorm undid the work, leaving struggling motor cars plowing axle deep in clayey West Virginia mud. Last March the upkeep of the dirt roads in the county cost $22,000, besides which the muddy roads caused expensive damages and delays. This is the 'mud tax,' which everyone must pay directly or indirectly. Permanent highways will mean higher taxes, but they will be more than repaid by increased real estate values and lowered transportation costs.

"The invention of the railroad during the early development of this country made it possible for the Nation to spread over vast territories in a few decades. A historian tells us that 12,000 wagons passed between Pittsburgh, Philadelphia, and Baltimore in 1817. This would make a week's traffic over the Pennsylvania Railroad now. The railroad situation is a vital problem to-day, for when transportation breaks down civilization can not stand. The country's needs have outgrown the railroads, and the motor truck on permanent highways seems to be the solution for our transportation problem.

"The agricultural population of a country is the foundation of its propperity. The influx of population to our cities is the most characteristic movement of to-day and is largely caused by the isolation of farm life. Good roads and the family car give the farmer's family social advantages and make possible a consolidated school and central church for the farm district.

"The problem of the 'high cost of living' is largely a distribution problem. Transportation takes toll from every consumer. With hard-surface roads a team or truck can pull ten times as great a load as on muddy roads, and the farmer can move his crops in accordance with the market rather than the condition of the roads, thus reducing storage costs and discouraging speculation. Good roads lower living costs by keeping the producer on the farm and widening the area of productive cultivation.

"Since the beginning of the World War vacation travel has been diverted to tours in our own country, resulting in a quickening of interest in road improvement. With the increase in automobiles and extension of national highways tourist travel has increased rapidly, expending money at home rather than abroad and promoting national unity and intelligent patriotism.

"Ever since the Romans linked their empire together with roads that endure to the present day military leaders have recognized the importance of good roads. Motor busses on the splendid highways of France brought up the reserves in time to save the Allies at Verdun. When the railroads of our country were burdened with war-time traffic and embargoes were placed on nonessentials, the motor truck was extensively used to relieve the freight congestion. Money invested in good roads pays as high dividends in peace as in war. Truly this is a form of preparedness which all can indorse."

[Continued from page 18.]

shown already that such movement occurs daily as a result of temperature changes.[2]

The determination of the edge and corner resistance of the slab presents no great difficulty. It is confidently expected that reliable data on this subject will be developed by tests now under way; and with the knowledge gained it should not be a difficult matter to design all parts of the slab to have equal strength.

What doubt remains as to the intensity of the impact which may be delivered by vehicles operating on actual roads should be cleared up by means of the impact recorder designed by the bureau and awaiting only minor adjustments preparatory to experimental use. This apparatus, attached to a motor truck, will give autographic space-time curves similar to those drawn by the instrument attached to the stationary impact machine, and thereby permit the measurement of impact on actual highway surfaces.

Other tests which are already in progress will yield further data on the resistance offered by bituminous-topped and reinforced-concrete pavements. If the subgrade problem can be solved satisfactorily the information which will ultimately become available should give a very clear conception of the type and thickness of pavement necessary for any given kind of traffic.

[2] "Subgrade Drainage Tests Yield Interesting Preliminary Data." Article by Ira B. Mullis. Public Roads, October, 1921.

[Continued from page 21.]

vorable soil conditions. Several samples taken along the road show that the soil grades about midway between the sandy soils of Ross County and the heavy clay soils of Trumbull and Cuyahoga Counties. The excellent natural drainage afforded by the rolling country through which the road passes is probably largely responsible for the fact that no major foundation failures have occurred. There are no closed depressions or swamps to hold the water in the subgrade and thus lessen its bearing power.

In northeastern Ohio a somewhat wider range of conditions is encountered. Probably the worst combination of poor soil and poor drainage with heavy traffic was observed in Trumbull County. Here the road ran through a very flat country permitting almost no natural drainage, while the soil was a very heavy clay. Its analysis is shown as No. 159. In the face of such conditions it is remarkable that the road has held as well as it has.

In summing up, a study of these roads would seem to warrant the following conclusions:

That the "rolled-base" type, provided it is properly placed and compacted, is a suitable type for brick construction where soil conditions are favorable and good natural drainage may be obtained. Under these conditions a 6-inch compacted rolled base should be adequate, provided a 2-inch sand or screenings cushion is used.

That the rolled base may be successfully used under ordinary road conditions, provided the thickness of the base is adjusted to meet the probable traffic requirements. An 8-inch to 10-inch compacted base with an additional 2 inches of cushion should suffice under all but trunkline highways subjected to very heavy traffic.

That whenever a rolled base is used a bituminous rather than a grout filler should be employed in order to provide a flexible section throughout.

That in general asphalt fillers are more satisfactory than tar or tar-mastic fillers, owing to the tendency of the latter either to chip out or flow in hot weather, leaving the edges of the brick unprotected.

That very inferior material as measured by laboratory tests may be successfully used as base material for brick roads.

[Continued from page 24.]

7½ inches long, to be used at the ends of the bridges, and the other, 11 feet 3 inches long, to be used as intermediate sections. Floor beams and stringers are included. The sections are uniformly 5 feet 11 inches deep, and when erected according to the Army plans the trusses are spaced 14 feet apart and provide for an 11-foot roadway. They were designed to carry trucks and heavy artillery and will safely carry trucks of 15 tons gross weight for spans up to 114 feet.

The field connections are made with 1-inch bolts which are shipped with the trusses, so that all necessary material is at hand when the sections arrive at the job. After the abutments are completed a bridge can be erected under favorable conditions in a few days at a cost of about $200.

MATERIAL A GODSEND TO SOME STATES.

The general attitude of the States toward the distribution of this material was recently manifested in a resolution of the executive committee of the American Association of State Highway Officials expressing the appreciation of the State departments. How valuable it has been to some of the States is shown by a recent statement issued by the Nebraska Department of Public Works, which says in part, "Financially the State of Nebraska was saved thousands of dollars by the receipt of the material, for by being in a position with our own construction organization [made up of this equipment] to take any contract at any time, we were able to force the keenest kind of competition and reduce bid prices to as low as or lower than those received in other States.

"Second, with regard to mileage built, 60 per cent of the road work completed this year in the State would have been totally untouched had the equipment not been available. Nearly 1,500 miles were constructed by gangs outfitted with this equipment."

UNIV. OF MICHIGAN OFFERS SHORT COURSE IN HIGHWAY ENGINEERING AND TRANSPORT

The University of Michigan announces that it will offer short courses for men engaged in the practice of highway engineering and highway transport. The courses will be given in periods of two weeks each from December, 1921, to March, 1922. A man may take one course or a group of courses.

The courses will cover the design and construction of the various types of roads, highway management and finance, transport legislation, traffic regulation, transportation costs and related subjects.

For further information write to A. H. Blanchard, University of Michigan, Ann Arbor, Mich.

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FEDERAL-AID ALLOWANCES

PROJECT STATEMENTS APPROVED IN SEPTEMBER, 1921

State.	Project No.	County.	Length in miles.	Type of construction.	Project statement approved.	Estimated cost.	Federal aid.
Alabama	103	Tuscaloosa	Bridge.	Steel span	Sept. 12	$232,746.62	$116,373.31
	105	Colbert	14.670	Gravel	Aug. 31	148,272.85	74,136.42
	106	Mobile	4.664	Concrete, sheet asphalt, or bituminous concrete	Sept. 29	168,608.00	84,304.00
Arkansas	37	Washington	19.820	Gravel	Sept. 1	83,723.05	41,750.00
Colorado	133	Adams	4.318	Concrete	Aug. 24	169,996.97	84,998.48
	173	Pueblo	Bridge.	Steel truss	Sept. 7	27,500.00	13,750.00
Idaho	23	Twin Falls	[1] 14.940	Bituminous concrete	Sept. 29	[1] 25,931.18	[1] 65,846.31
Indiana	24	Hamilton and Tipton	25.653	Brick, bituminous, or concrete	Sept. 7	1,002,485.00	501,242.50
	30	Noble	.912	Brick, concrete, or bituminous concrete	Sept. 27	61,351.84	18,240.00
Kansas	90	Butler	10.500	Earth	Sept. 2	88,990.00	31,500.00
	91	Geary	.716	Bituminous filled brick or bituminous concrete	Sept. 14	38,412.00	10,740.00
	92	Republic	9.080	Earth	Sept. 6	72,198.50	22,500.00
	93	Leavenworth	.500	Concrete	do	26,312.00	7,500.00
	94	do	2.180	do	Sept. 7	156,851.42	20,000.00
Kentucky	58	McCracken	2.390	Gravel and Kentucky rock asphalt	Sept. 24	41,321.50	20,660.75
	64	Livingston	12.000	Gravel	do	226,820.00	113,410.00
	37	Rowan	9.000	Earth	Sept. 7	135,300.00	67,650.00
Maryland	2	Prince Georges	[1] 1.070	Concrete	Sept. 20	[1] 36,353.97	[1] 3,634.39
	31	Charles	[1] 6.130	Gravel	Sept. 22	[1] 127,579.21	[1] 63,789.61
	36	Anne Arundel	[1] 1.860	Concrete	Sept. 21	[1] 71,576.11	[1] 7,157.61
	37	Queen Annes	[1] 2.010	do	do	[1] 65,558.90	[1] 6,555.89
Massachusetts	70	Hampden	2.550	Bituminous macadam	Aug. 29	133,650.00	51,000.00
Michigan	52	Kalamazoo	6.382	Concrete or bituminous concrete	Sept. 10	253,056.65	126,528.32
Minnesota	106	Benton	[2] .73	Gravel	do	[1] 457,877.70	[1] 280,386.58
	171	St. Louis		Earth	Sept. 30	[1] 40,095.36	[1] 10,200.00
	207	Olmstead	6.030	Gravel	Sept. 12	115,353.35	10,000.00
	208	Meeker	2.050	do	Sept. 10	45,225.77	5,000.00
	209	Stearns	2.860	do	do	29,156.25	5,000.00
	214	Lyon	17.820	do	Sept. 12	94,994.03	10,000.00
	216	Blue Earth	11.300	do	do	117,067.43	10,000.00
	218	Wabasha	7.340	do	do	161,640.41	10,000.00
	219	Cass	3.800	do	do	23,472.58	5,000.00
	220	Isanti	4.830	do	do	43,697.50	5,000.00
	222	Ottertail	14.500	do	do	162,165.00	10,000.00
	223	Sherburne	2.810	do	do	20,550.68	5,000.00
Mississippi	68	Yazoo	8.460	do	Aug. 29	126,593.50	63,795.75
Missouri	181	Osage	2.650	do	Sept. 30	[2] 17,938.72	[2] 8,959.36
Montana	153	Phillips	8.000	do	Sept. 12	69,960.00	34,980.00
	166	Gallatin and Park	3.030	do	Sept. 13	77,728.75	38,864.37
Nebraska	110	Boyd and Knox	[1] 35.200	Sand-clay	Sept. 27	[1] 43,993.92	[1] 21,996.96
	116	Nemaha	[1] 12.000	Earth	Sept. 7	[1] 43,340.00	[1] 21,670.00
New Hampshire	136	Coos	2.620	Gravel	Sept. 12	20,472.76	10,236.38
	137	Rockingham	1.910	do	Sept. 24	30,000.00	15,000.00
New Mexico	71	Chaves	1.500	do	do	21,467.60	10,733.80
	72	San Miguel	9.500	Gravel or crushed rock	do	56,067.00	28,033.50
	73	Socorro	8.000	do	Sept. 7	42,904.40	21,452.20
	81	Colfax	13.300	Gravel	Sept. 24	47,190.00	23,595.00
New York	157	Erie	7.930	Bituminous macadam	Sept. 10	188,500.00	94,250.00
North Dakota	116	Walsh	15.000	Earth	Aug. 29	47,300.00	23,650.00
Ohio	206	Geauga	4.971	Concrete	Sept. 12	190,000.00	87,500.00
	212	Lake	Bridge.	do	Sept. 6	106,000.00	53,000.00
	215	Stock	.904	Brick	Sept. 12	60,000.00	15,000.00
	221	Putnam	2.719	Kentucky rock asphalt	do	107,000.00	25,000.00
Oregon	53	Clackamas	3.750	Concrete	Sept. 13	119,766.90	33,171.64
South Carolina	63	Berkeley	1.193	Sand-clay	Oct. 3	21,140.37	10,000.00
	116	Charleston	.999	do	do	18,876.19	9,439.09
	117	Barnwell	9.968	do	Aug. 27	40,096.50	20,048.25
	136	Marlboro	Bridge.		Aug. 29	12,056.05	6,028.02
	124	Charleston	7.877	Sand-clay	do	33,026.77	16,513.38
	125	McCormick	16.174	Top soil	Sept. 30	39,030.20	19,515.10
	126	Fairfield	4.849	do	Sept. 6	21,555.63	10,777.81
	137	Anderson	8.086	do	Sept. 30	15,349.40	5,500.00
	138	do	3.856	do	do	13,018.67	6,509.33
	131	Orangeburg	19.885	Sand-clay	Sept. 10	59,806.69	29,903.34
South Dakota	81	Beadle	13.800	Gravel	Sept. 7	97,977.00	48,988.50
	83	Kingsbury	15.520	do	Sept. 22	85,276.40	42,638.20
	84	Spink	9.470	Earth	Sept. 24	31,262.00	15,631.00
Texas	38	Lamar	[2] 4.620	Gravel	Sept. 12	[2] 151,748.22	[2] 41,000.00
	151	Bee	[2] 19.063	Gravel, bituminous top	Sept. 1	[2] 417,569.97	[2] 50,000.00
	187	Bastrop	[1] 1.353	Gravel	Aug. 29	[2] 39,764.83	[2] 113.20
	191	Milam	[2] 6.933	do	Sept. 22	[2] 65,077.82	[2] 53,625.44
	209	Bexar	3.344	Gravel, bituminous top	Sept. 7	82,661.61	41,330.80
	244	Blanco	14.200	Earth	Sept. 24	69,999.99	17,500.00
	246	Comal	17.250	Gravel and macadam	do	103,500.79	25,875.19
Utah	19	Garfield	[1] 33.020	Earth and gravel	Sept. 10	[1] 169,525.24	[1] 84,762.62
	25	Utah and Juab	[1] 8.040	Concrete	do	[1] 68,789.71	[1] 34,394.85
	27	Cache	[1] 3.780	do	do	[1] 80,056.33	[1] 40,028.16
	37	Utah	1.351	do	Sept. 29	50,800.20	25,400.10
Virginia	95	Rockingham	2.100	Bituminous macadam	Sept. 24	48,033.08	24,016.54
Washington	85	Thurston	8.520	Concrete	Sept. 7	351,791.21	1,000.00
Wisconsin	201	Douglas	2.400	Gravel	Sept. 3	29,297.56	12,679.49
	260	Polk	3.450	do	Sept. 9	24,144.27	10,000.00

[1] Revised statement. Amounts given are decreases over those in the original statement.
[2] Revised statement. Amounts given are increases over those in the original statement.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS.

Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets, nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.

REPORTS.

Report of the Director of the Bureau of Public Roads for 1918.
Report of the Chief of the Bureau of Public Roads for 1919.
Report of the Chief of the Bureau of Public Roads for 1920.
Report of the Chief of the Bureau of Public Roads for 1921.

DEPARTMENT BULLETINS.

Dept. Bul. *105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913. 5c.
*136. Highway Bonds. 25c.
220. Road Models.
*249. Portland Cement Concrete Pavements for Country Roads. 15c.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
314. Methods for the Examination of Bituminous Road Materials.
347. Methods for the Determination of the Physical Properties of Road-Building Rock.
*370. The Results of Physical Tests of Road-Building Rock. 15c.
*373. Brick Roads. 15c.
386. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387. Public Road Mileage and Revenues in the Southern States, 1914.
388. Public Road Mileage and Revenues in the New England States, 1914.
*389. Public Road Mileage and Revenues in the Central, Mountain, and Pacific States, 1914. 15c.
390. Public Road Mileage in the United States, 1914. A Summary.
393. Economic Surveys of County Highway Improvement.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
414. Convict Labor for Road Work.
*463. Earth, Sand-Clay, and Gravel Roads. 15c.
*532. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537. The Results of Physical Tests of Road-Building Rock in 1916, including all Compression Tests. 5c.
*555. Standard Forms for Specifications, Tests, Reports, and Methods of Sampling for Road Materials. 10c.
583. Reports on Experimental Convict Road Camp, Fulton County, Ga.
586. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1916.
*660. Highway Cost Keeping. 10c.
670. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691. Typical Specifications for Bituminous Road Materials. 15c.
704. Typical Specifications for Nonbituminous Road Materials.
*724. Drainage Methods and Foundations for County Roads. 20c.
949. Standard and Tentative Methods of Sampling and Testing Highway Materials.

*Public Roads. Vol. II, No. 23. Tests of Road-Building Rock in 1919. 15c.
Public Roads. Vol. IV, No. 2. Tests of Road-Building Rock in 1920.

DEPARTMENT CIRCULAR.

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS.

F. B. 338. Macadam Roads.
505. Benefits of Improved Roads.
597. The Road Drag.

SEPARATE REPRINTS FROM THE YEARBOOK.

Y. B. Sept. *727. Design of Public Roads. 5c.
739. Federal Aid to Highways.
849. Roads.

OFFICE OF PUBLIC ROADS BULLETINS.

Bul. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF PUBLIC ROADS CIRCULAR.

Cir. *89. Progress Report of Experiments with Dust Preventatives, 1907. 5c.
*90. Progress Report of Experiments in Dust Prevention, Road Preservation, and Road Construction, 1908. 5c.
*92. Progress Report of Experiments in Dust Prevention and Road Preservation, 1909. 5c.
*94. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1910. 5c.
*99. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1912. 5c.

OFFICE OF THE SECRETARY CIRCULARS.

Sec. Cir. 49. Motor Vehicle Registrations and Revenues, 1914.
59. Automobile Registrations, Licenses, and Revenues in the United States, 1915.
63. State Highway Mileage and Expenditures to January 1, 1916.
*65. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Aid Road Act. 5c.
*72. Width of Wagon Tires Recommended for Loads of Varying Magnitude on Earth and Gravel Roads. 5c.
73. Automobile Registrations, Licenses, and Revenues in the United States, 1916.
74. State Highway Mileage and Expenditures for the Calendar Year 1916.
*77. Experimental Roads in the Vicinity of Washington, D. C. 5c.

Public Roads Vol. I, No. 1. Automobile Registrations, Licenses, and Revenues in the United States, 1917.
Vol. I, No. 3. State Highway Mileage and Expenditures in the United States, 1917
Vol. III, No. 25. Automobile Registrations, Licenses, and Revenues in the United States, 1919.
Vol. III, No. 29. State Highway mileage, 1919.
Vol. III, No. 36. Automobile Registrations, Licenses, and Revenues in the United States, 1920.
Vol. IV, No. 5. Automobile Registrations, Jan 1. to July 1, 1921.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH.

Vol. 5, No. 19, D-3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.
Vol. 5, No. 20, D-4. Apparatus for Measuring the Wear of Concrete Roads.
Vol. 5, No. 24, D-6. A New Penetration Needle for Use in Testing Bituminous Materials.
Vol. 10, No. 7, D-13. Toughness of Bituminous Aggregates.
Vol. 17, No. 4, D-16. Ultra-Microscopic Examination of Disperse Colloids Present in Bituminous Road Materials.

* Department supply exhausted.