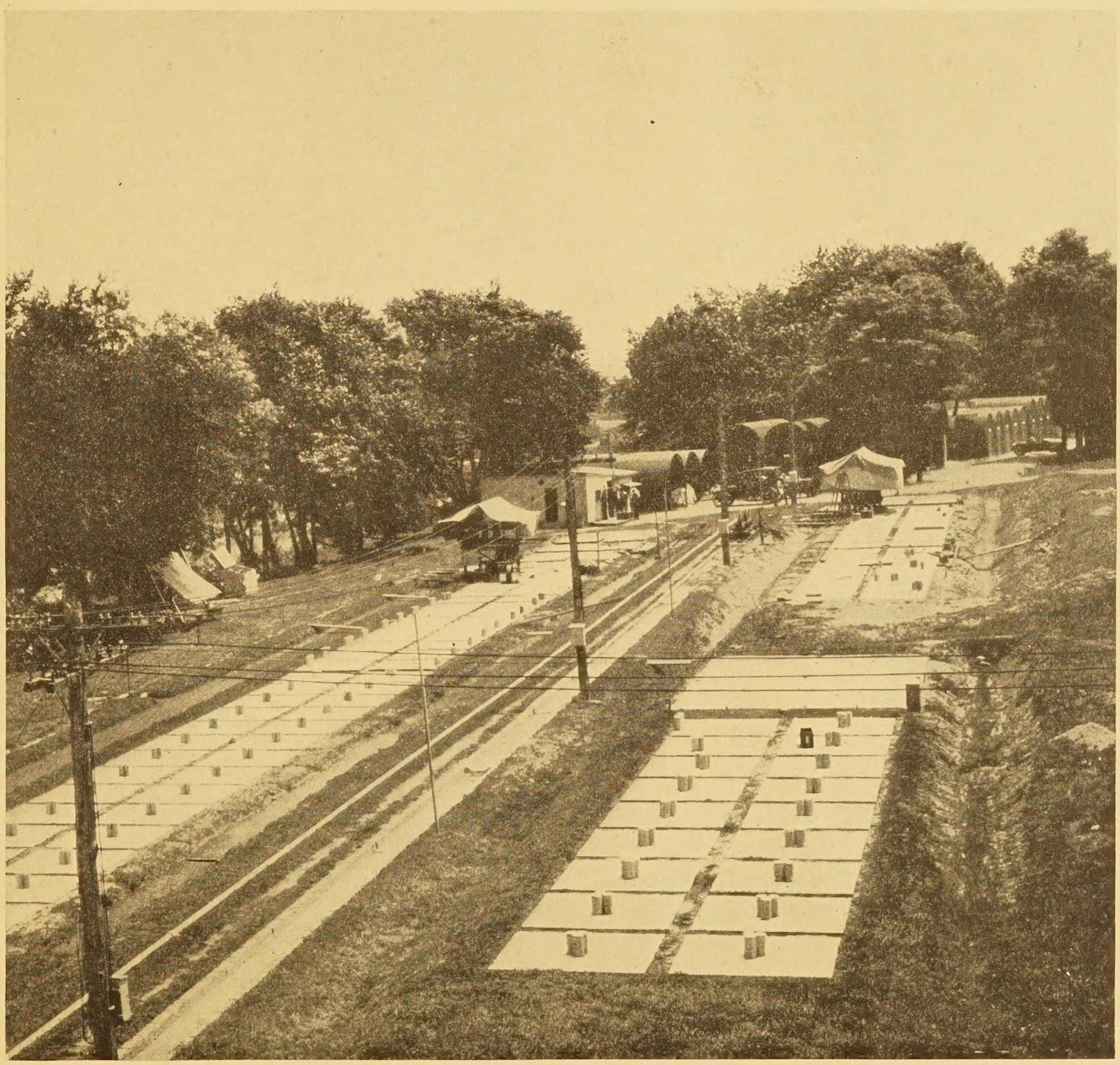
PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 5, NO. 2 ▽ APRIL, 1924



GENERAL VIEW OF SLABS FOR IMPACT TEST, ARLINGTON, VA.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1924

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH
U. S. DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

VOL. 5, NO. 2 | APRIL, 1924 | H. S. FAIRBANK, Editor

TABLE OF CONTENTS

THE U. S. BUREAU OF PUBLIC ROADS

Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS,
Bay Building, San Francisco, Calif.

DISTRICT OFFICES

DISTRICT No. 1, Oregon, Washington, Montana, and Alaska.
Box 3900, Portland, Oreg.

DISTRICT No. 2, California and Nevada.
Bay Building, San Francisco, Calif.

DISTRICT No. 3, Colorado and Wyoming.
301 Customhouse Building, Denver, Colo.

DISTRICT No. 4, Minnesota, North Dakota, South Dakota, and Wisconsin.
410 Hamm Building, St. Paul, Minn.

DISTRICT No. 5, Iowa, Kansas, Missouri, and Nebraska.
Webster-Sunderland Building, Omaha, Nebr.

DISTRICT No. 6, Arkansas, Louisiana, Oklahoma, and Texas.
1912 F. & M. Bank Building, Fort Worth, Tex.

DISTRICT No. 7, Illinois, Indiana, Kentucky, and Michigan.
South Chicago Station, Chicago, Ill.

DISTRICT No. 8, Alabama, Georgia, Florida, Mississippi, South Carolina, and Tennessee.
Box J, Montgomery, Ala.

DISTRICT No. 9, Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
Federal Building, Troy, N. Y.

DISTRICT No. 10, Delaware, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia.
Willard Building, Washington, D. C.

DISTRICT No. 12, Idaho and Utah.
Fred J. Kiesel Building, Ogden, Utah.

DISTRICT No. 13, Arizona and New Mexico.
242 West Washington St., Phoenix, Ariz.

Owing to the necessarily limited edition of this publication it will be impossible to distribute it free to any persons or institutions other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, periodicals upon an exchange basis, and Members of both Houses of Congress. Others desiring to obtain "Public Roads" can do so by sending 10 cents for a single number or $1 per year to the Superintendent of Documents, Government Printing Office, Washington, D. C.

IMPACT TESTS ON CONCRETE PAVEMENT SLABS.

RESISTANCE OF VARIOUS DESIGNS DETERMINED BY BUREAU OF PUBLIC ROADS EXPERIMENTS.

By LESLIE W. TELLER, Assistant Testing Engineer, U. S. Bureau of Public Roads.

CONTINUING the study of the magnitude and effect of motor truck impact begun four years ago, the Bureau of Public Roads has recently completed a series of tests to determine the resistance of pavement slabs of various designs to impact of motor vehicles. Previous reports dealing with earlier phases of the investigation have announced the findings of the bureau with respect to the possible magnitude of the impact forces resulting from the operation of trucks over road surfaces of different degrees of roughness, the relative strength of such forces compared with the static weight of the vehicle, the effect of differences in tire and spring equipment and variations in sprung and unsprung load upon the character and intensity of the impact, and the effect of the impact upon a limited number of specially constructed slabs of various designs.[1]

This report deals with the results of the tests of a second series of slabs more comprehensive in its range of types. As in the case of the previous reports, this one deals with only one phase of the investigation which is being continued. The results reported are not entirely conclusive. They are to be regarded as sign boards which point the way rather than as a guaranty of safe arrival at the destination. If viewed thus broadly, it is felt that their publication will accomplish a useful purpose.

Some of the results are erratic and in the absence of check tests can not be explained, but in the main they are quite consistent. Some of the indications are apparent throughout the tests, while others do not show so clearly in the data, and in such cases careful observations made in the course of the tests and the knowledge of the investigators as to conditions which influenced the results of individual tests have been drawn upon as well as the recorded test data in forming the conclusions which are presented below.

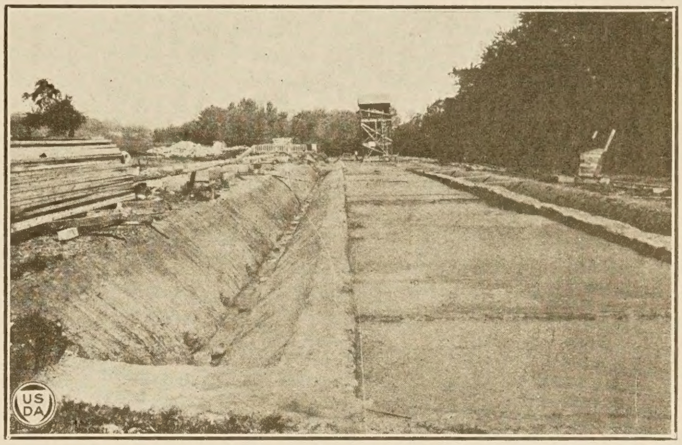
CONCLUSIONS DRAWN FROM THE TESTS.

The exact nature of the tests must be borne in mind in applying the conclusions drawn from them to other conditions. The conclusions are stated in terms of maximum impacts delivered by the different weights of motor truck. Failure is assumed to have occurred when cracking takes place. The maximum impact values are such as would be expected under conditions of high speed and rough surface. Smoothness of the surface and suitable tire equipment will reduce the maximum impact pressures with a resulting higher load carrying capacity than that indicated by the tests.

The essential features of the tests involve:

(1) Specimens 7 feet square laid on a moderately plastic clay subgrade, the wet portion having water standing almost level with the surface, the dry portion being merely damp with capillary moisture.

(2) Repeated impacts increasing to the maximum which caused cracking applied at the corner and at the center of one edge by an impact machine dealing blows closely resembling impact of motor trucks. Rolling loads were not applied. No impacts were delivered at the centers of the slabs.



Construction view—wet subgrade section showing tile cross drains and subgrade cut for slabs of various thickness.

The conclusions drawn from the test are as follows:

The resistance of the road slab depends in part upon the supporting value of the subgrade. A subgrade of high supporting value materially increases the resistance to impact.

Impact resistance of rigid slabs varies neither directly as the depth of the slab nor as the square of the depth but as some power less than two.

In general, plain concrete slabs show no more resistance to impact delivered at the edge than to impact delivered at a corner.

Transverse cracks and longitudinal cracks near the sides of a road slab may be caused by impact delivered at the edge of the slab.

Plain concrete of 1:3:6 mix offers resistance to impact ranging from about 60 per cent to 80 per cent of the resistance of plain concrete of 1:1½:3 mix. The lean mix also shows more variation in strength.

Reinforcing steel in concrete slabs, if present in sufficient amount and so placed as to receive tensile stress, adds to the resistance of the slab to impact.

Reinforcing steel placed longitudinally and transversely in equal percentages is more effective in preventing corner failures than the same amount placed in one direction.

For a given percentage of steel, small deformed rods closely spaced seem to be more effective than large deformed rods widely spaced.

There is very little evidence of cushioning by bituminous tops on concrete bases at temperatures of 90° F. or less.

In these tests there was no evidence that bituminous tops on concrete bases added to the slab strength of the base, with the possible exception of the 4-inch and 6-inch bases on the dry subgrade.

Laid on the wet plastic subgrade none of the unreinforced slabs was capable of resisting impact at the edge or corner equivalent to that of a 5-ton truck; only the 8-inch, 1:1½:3 slabs and the 2-inch Topeka

[1] Previous reports on these investigations will be found in several issues of Public Roads, as follows: Vol. 3, No. 35, March, 1921; Vol. 4, No. 6, October, 1921; Vol. 4, No. 7, November, 1921; and Vol. 4, No. 8, December, 1921.

93439—24——1

tops on 8-inch, 1: 1½: 3 bases resisted edge or corner impact equivalent to that of a 3-ton truck; all unreinforced slabs of lesser thickness failed under edge or corner impact less than that of a 2-ton truck.

Laid on a dry subgrade the 8-inch plain concrete slabs of 1: 1½: 3 mix and the 8-inch edge thickness, unreinforced, 1: 1½: 3 bases with 2-inch Topeka tops resisted edge and corner impact equivalent to that of a 5-ton truck with a safe margin; no other slabs were capable of resisting the 5-ton truck impact even under the favorable conditions of dry subgrade support. A section of 6-inch plain concrete base, 1: 1½: 3 mix, with a 2-inch Topeka top resisted the edge impact of a 3-ton truck; no other slabs of lesser edge thickness, laid on the dry subgrade, were capable of resisting impact greater than that of a 2-ton truck.

None of the systems of steel reinforcing tested added sufficiently to the strength of a 6-inch 1: 1½: 3 concrete slab to enable it to resist the edge and corner impact of a 3-ton truck when the slab was supported by a very wet, plastic subgrade, nor to resist the edge or corner impact of a 5-ton truck when the slab was supported by a dry subgrade.

In some of the tests there was evidence that while the presence of the steel did not assist greatly in preventing the formation of the first crack it did prevent the development of the crack and the further failure of the slab.

OBJECT AND ORDER OF THE TESTS.

The object of this series of tests which, like the other series, was conducted at the Arlington Experimental Farm, Arlington, Va., was to secure data on the comparative resistance of sections of various types of road slabs when subjected to impact forces of the same magnitude as those applied to actual roads by modern truck traffic of different weights.

To carry out this purpose three distinct steps were required, as follows:

1. The determination of the magnitude of the maximum impact to which a road slab is subjected by motor trucks of different sizes.
2. The application of similar impact forces to the test sections.
3. The measurement of the effect of these impacts on the various test sections.

In order to carry out the first step in the program, a series of about 100 road tests was run to determine the maximum impact to which a road slab is subjected when different sizes of motor trucks are driven over it, fully loaded and at their maximum speed.

At the present time, the Bureau of Public Roads is conducting a similar but much more elaborate series of tests to determine this and other information regarding actual motor truck impact. But for the purpose of the impact tests on pavement slabs the tests were limited to standard types of 2-ton, 3-ton, and 5-ton trucks. Standard equipment in the way of solid tires, wheels, springs, and spring suspension was used. These trucks were driven over typical concrete roads, maintained in good condition, and the maximum rear wheel impact was measured by means of an especially designed accelerometer.

DESCRIPTION OF THE TEST SECTIONS.

As in the first series of impact tests, the attempt was made to reproduce two subgrade conditions—a dry, well-drained type and a thoroughly saturated one. Extra precautions were taken to insure as much contrast as possible between the bearing values of the two subgrades.

One hundred and twenty-four slabs were laid, embracing in all about 40 different types. Each slab was laid in duplicate, and the more important types were placed on both the dry and the wet subgrades. All slabs were 7 feet square.

The types of slabs may be roughly divided into five groups:

1. Plain concrete.
2. Reinforced concrete.
3. Concrete bases and bituminous tops.
4. Bituminous bases and bituminous tops.
5. Macadam bases and bituminous tops.

Tests of the slabs of all five groups have been completed, but this report does not deal with the tests of bituminous tops on macadam and bituminous bases. The behavior of these slabs is materially different from that of the concrete slabs and the concrete bases with bituminous tops, and it is felt that the results of the tests of these groups should receive further study before they are announced.

A detailed description of each of the slabs in groups 1, 2, and 3 as to materials used, mixtures and thickness, is given in Table I.

TABLE I.—*Description of test slabs.*

(Series 222–267 laid on wet subgrade; Series 314–337 laid on dry subgrade; Series 1R–18R laid on dry subgrade.)

PLAIN CONCRETE SLABS AND BASES.

Slab No.	Base course.		Binder course.		Surface course.	
	Thickness.	Material.	Thickness.	Material.	Thickness.	Material.
	Inches.		*Inches.*		*Inches.*	
222	6	1:3:6 concrete.	1½	Bituminous concrete.	1½	Sheet asphalt.
223	6	do	1½	do	1½	Do.
224	6	do			4	Bituminous concrete.
225	6	do			4	Do.
226	6	do			2	Do.
227	6	do			2	Do.
228	4	do			2	Topeka.
229	4	do			2	Do.
230	4	1 : 1½ : 3 concrete.			2	Do.
231	4	do			2	Do.
232	6	1:3:6 concrete.			2	Do.
233	6	do			2	Do.
234	6	1 : 1½ : 3 concrete.			2	Do.
235	6	do			2	Do.
236	8	1:3:6 concrete.			2	Do.
237	8	do			2	Do.
238	8	1 : 1½ : 3 concrete.			2	Do.
239	8	do			2	Do.
240					4	1 : 1½ : 3 concrete.
241					4	Do.
242					6	Do.
243					6	Do.
244					6	1 : 3 : 6 concrete.
245					6	Do.
246					8	1 : 1½ : 3 concrete.
247					8	Do.
248					8	1 : 3 : 6 concrete.
249					8	Do.
314	6	1 : 1½ : 3 concrete.			2	Topeka.
315	6	do			2	Do.
316	6	1:3:6 con-			2	Do.
317	6	do			2	Do.
318	4	1 : 1½ : 3 concrete.			2	Do.
319	4	do			2	Do.
320	8	do			2	Do.
321	8	do			2	Do.
322					4	1 : 1½ : 3 concrete.
323					4	Do.
324					6	Do.
325					6	Do.
326					6	1 : 3 : 6 concrete.
327					6	Do.
328					8	1 : 1½ : 3 concrete.
329					8	Do.

TABLE I.—*Description of test slabs*—Continued.

CONCRETE SLABS WITH MESH REINFORCING—WET SUBGRADE.

Slab No.	Surface course.			
	Thickness.	Material.	Reinforcement.	
			Description.	Per cent.
	Inches.			
250	4	1: 1½: 3 concrete	1 layer No. 6	0.21
251	4	do	do	.21
252	4	do	2 layers No. 6	.42
253	4	do	do	.42
254	4	do	2 layers No. 8	.66
255	4	do	do	.66
256	4	do	1 layer No. 10	.41
257	4	do	do	.41
258	4	do	2 layers No. 10	.82
259	4	do	do	.82
260	6	do	1 layer No. 6	.19
261	6	do	do	.19
262	6	do	2 layers No. 6	.38
263	6	do	do	.38
264	6	do	2 layers No. 8	.46
265	6	do	do	.46
266	6	do	2 layers No. 10	.58
267	6	do	do	.58

CONCRETE SLABS WITH MESH REINFORCING—DRY SUBGRADE.

	Inches.			
330	4	1: 1½: 3 concrete	1 layer No. 6	0.21
331	4	do	do	.21
332	4	do	1 layer No. 10	.41
333	4	do	do	.41
334	6	do	2 layers No. 6	.38
335	6	do	do	.38
336	6	do	2 layers No. 8	.46
337	6	do	do	.46

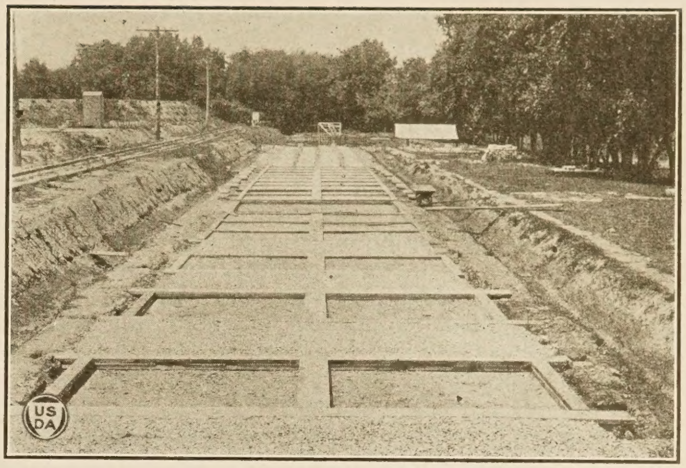
CONCRETE SLABS WITH ROD REINFORCING—DRY SUBGRADE.

Slab No.	Surface course.					
	Thickness.	Material.	Reinforcement.			
			Number of layers.	Size of rods.	Spacing of rods center to center.	Per cent.
	Inches.			*Inch.*	*Inches.*	
1–R	6	1: 1½: 3 concrete	1	3/8	3¾	0.5
2–R	6	do	1	3/8	3¾	.5
3–R	6	do	2	3/8	3¾	1.0
4–R	6	do	2	3/8	3¾	1.0
5–R	6	do	2	3/8	7⅜	.5
6–R	6	do	2	3/8	7⅜	.5
7–R	6	do	1	5/8	10¼	.5
8–R	6	do	1	5/8	10¼	.5
9–R	6	do	2	5/8	10¼	1.0
10–R	6	do	2	5/8	10¼	1.0
11–R	6	do	2	5/8	20½	.5
12–R	6	do	2	5/8	20½	.5
13–R	6	do	1	7/8	20	.5
14–R	6	do	1	7/8	20	.5
15–R	6	do	2	7/8	20	1.0
16–R	6	do	2	7/8	20	1.0
17–R	6	do	2	7/8	40	.5
18–R	6	do	2	7/8	40	.5

CONSTRUCTION OF THE TEST SECTIONS.

Every effort was made to have each slab built exactly according to specifications. The subgrade on which the slabs rest was brought to grade by cutting. No fills were permitted. In the wet subgrade, a tile drain was placed transversely, every eight feet, connecting the longitudinal side ditches. These tile lines came between slabs so as not to disturb the soil under the slabs and their function was to lead water from the side ditches back into the subgrade.

All concrete was mixed in a standard gasoline-driven mixer, the materials being measured in a cubic-foot measure. The coarse aggregate used was washed, Potomac River gravel and the fine aggregate a good quality of concrete sand purchased locally. As soon as the concrete was poured it was protected with canvas until the following morning when it was covered with earth and kept wet for two weeks. Curing was completed by exposure to the air.



Construction view—wet subgrade section, bases laid and forms for bituminous material in place.

Three 6 by 12 inch compression cylinders were made of the concrete as it came from the mixer and these were cured in the same manner as the slab.

All concrete was placed rather dry and was finished by striking off flush with the forms with a screed. No troweling was permitted.

The plans called for all steel in the reinforced slabs to be placed 2 inches from the top surface of the slabs. For the reinforcing itself, except in the rod-reinforced sections, a fabric type was used—rods one way 6 inches apart, held together with perpendicular wire cross members every 12 inches. The cross members were not welded to the rods, but were attached to them with wire clips. Greater bond strength would probably have been developed had these members been electrically welded. When two layers of reinforcing were used, the rods were placed at right angles to each other with one sheet laid directly on the other. Test on this steel showed it to be an intermediate grade steel with an ultimate strength of 70,000 pounds. In sections 1–R to 18–R, square, deformed bars were used, the sizes and spacing being given in Table I.

After the concrete had cured for one year, the bituminous slabs were laid. This was done by contract, the material being mixed and placed under the supervision of the Bureau of Public Roads.

Four and six inch concrete bases on the wet-subgrade sections were cracked in rolling the bituminous tops, the lean mixes being badly broken up. This unfortunate occurrence eliminated several very interesting sections from the tests, but it is worth noting that 6-inch 1 : 1½ : 3 concrete bases were cracked in construction where a fairly bad subgrade condition obtained, while 4 inch bases of the same mix withstood the same roller loads undamaged on a good subgrade. While the ditches surrounding the wet-subgrade sections had not been filled with water up to the time the rolling took place, the position of these sections at the foot of the hill and the presence of capillary water created a naturally poorer subgrade condition than that which existed in the dry-subgrade sections.

TESTING THE SLABS.

The second step in the program called for the application of impact to the test sections. The testing was begun in May, 1923. Prior to this time the ditches surrounding the wet subgrades had for several months been kept filled with water to the level of the under side of the 6 inch slabs. The magnitude of the impact forces to be applied had previously been determined by the preliminary road tests using actual motor trucks. As it was obviously impracticable to use a motor truck for testing the slabs, a special portable impact machine was designed and two of them were built.

THE IMPACT MACHINE.

This machine, which is shown in the accompanying illustration, consists essentially of a rear wheel of a motor truck fastened solidly to the middle of a truck spring and so arranged that it can be raised to any desired height from the surface under test and dropped suddenly. Power is furnished by an electric motor which operates through a train of gears, raising the wheel by means of a pair of cams. The whole mechanism is suitably mounted on a framework of structural steel.

Adjustments permit changing tire, wheel, spring, sprung weight, unsprung weight, or height of drop at will. The impact machine proved to be very satisfactory and reliable and no trouble was experienced from this source throughout the tests.

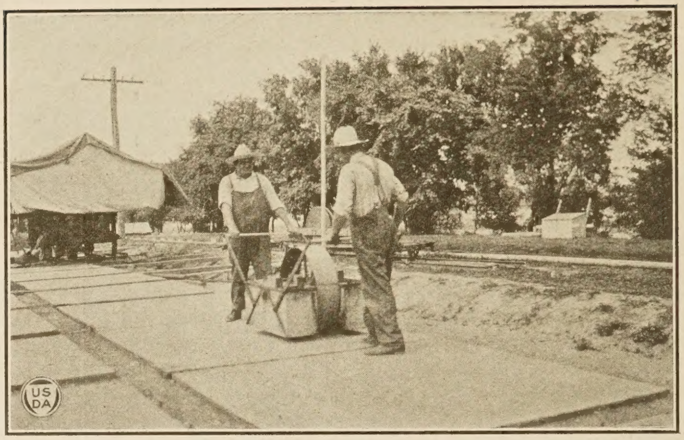
Load conditions corresponding to those of 2-ton, 3-ton, and 5-ton trucks were used.

THE METHOD OF TEST.

In testing a slab the machine was set up so that the wheel was over the point where the load was to be applied. The unsprung weight was made to correspond to that of a 2-ton truck. By means of the corner screws the machine was next set for a very low drop, usually one-quarter inch or less. The truck spring was then loaded to equal the sprung load of the same truck. This was done by pulling down the ends of the spring with screws until its deflection indicated the required sprung load. From three to five blows were delivered, after which the machine was raised slightly and three to five blows were again delivered at the new height. Each time the machine was raised it was necessary to pull the ends of the spring down an equal amount so that the spring deflection would remain constant. This procedure was continued until the data indicated that the maximum impact of which this weight of truck was capable had been delivered. If the slab had not failed, the loadings were increased to those of a 3-ton truck and corresponding impacts delivered. If a 5-ton truck impact failed to break the slab, the impacts were increased until failure occurred.

POINTS OF LOADING USED.

As the data desired were only comparative, it was originally intended to test one of each pair of slabs at the center point and the other one at the corner. But road tests indicated that the edge of a slab was one of its weakest points. Also, the testing of the first series of slabs had shown that for small slabs center resistances are dependent upon the area of the slab.[1] With these points in mind, it seemed that more and better information could be obtained by testing not at the center of the slab but at the center of the edge. The results show this to be true. These are called edge tests in the data.



Rolling asphalt tops. Roller weight, 250 pounds per inch of width.

In the corner tests the load was applied as near to the corner as it was possible to get the wheel and still have the area of contact entirely on the slab. This means the center of the wheel was over a point which was about 7 inches back from the corner, measuring along the diagonal of the slab.

DATA OBTAINED.

To compare the various slabs it was necessary to know the maximum impact applied to the slab by the wheel as it comes down and strikes the surface. There are several ways of doing this, all of which have been used at different times in connection with these tests. Among these methods may be mentioned: (1) A space-time curve; (2) copper-cylinder method; (3) deformation of spherical steel surface (Kreuger apparatus); and (4) mass × acceleration method, measuring the acceleration with an accelerometer.[2]

The first method is probably the most precise and the most difficult to use successfully. Because of the time required, it is impracticable for such tests as these. The second method is an approximation, as it introduces a new factor for which correction can not readily be made; i. e., the cushioning effect of the cylinder itself. The third method offers practical difficulties which render it unsuitable for this work.

By far the most satisfactory method is the mass × acceleration method, using an accelerometer to measure the acceleration. For this purpose a special accelerometer was used, which was devised and developed in the Bureau of Public Roads. This instrument is described in Proceedings of the American Society for Testing Materials, 1923, "An accelerometer for measuring impact," by E. B. Smith. In use it gives a reading which indicates the maximum negative acceleration which occurs when the falling truck wheel is brought to rest by the resistance of the slab. Knowing the unsprung weight of the impact machine, it is a simple matter to calculate the maximum impact by means of the formula

---

[1] Public Roads, Vol. 4, No. 7, November, 1921. "Tests of impact on pavements by the Bureau of Public Roads."

[2] For descriptions of these methods see Public Roads, Vol. 4, No. 6, October, 1921. "Tests of impact on pavements by the Bureau of Public Roads."

$$F = Ma \div P$$

in which F = Maximum force (impact).

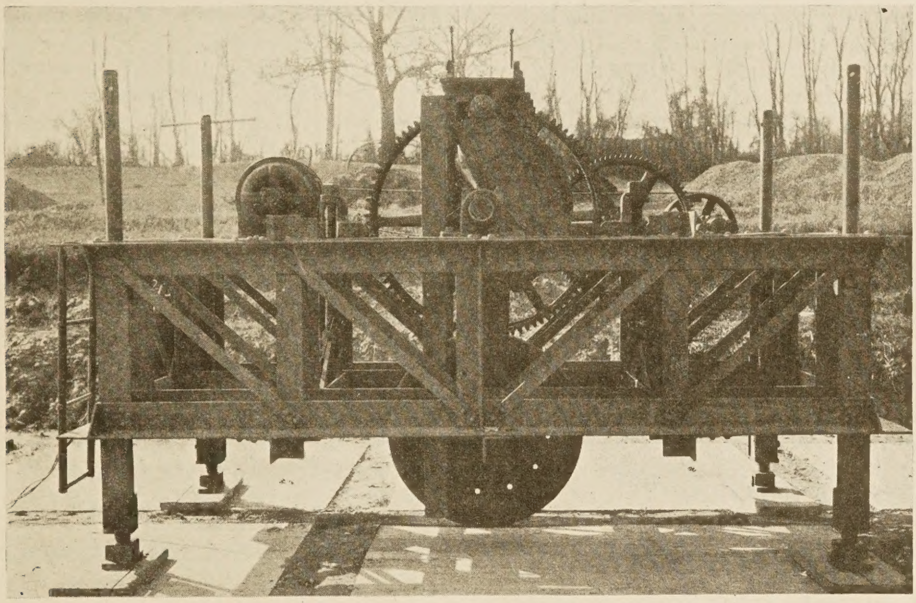
$M = \frac{W}{g}$ = weight of unsprung portion divided by 32.2.

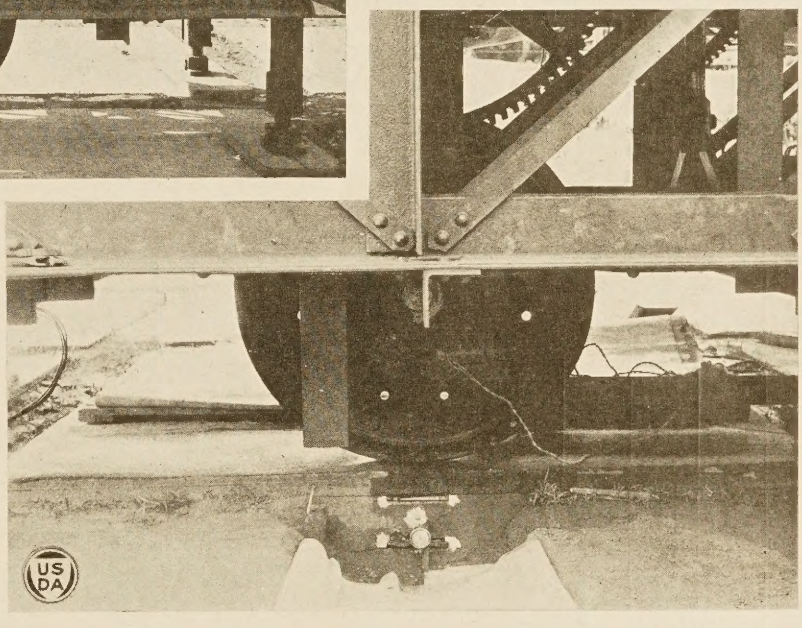
P = spring pressure existing when wheel is in contact with slab.

In practice this method has proved to be easy to use and sufficiently accurate for all practical purposes. Inasmuch as the accelerometer was actually mounted on a motor truck in the preliminary road tests, previously described, and certain readings obtained and then later it was mounted on the impact machine where the sprung and unsprung weight conditions of the truck were duplicated, it seems reasonable to assume that impacts which, under these two conditions, give equal accelerometer readings are equal in magnitude.

The effect of the impact is to deflect the slab. It is necessary, therefore, to measure the amount of this deflection. An Ames dial reading to one-thousandth of an inch and "choked" to hold its maximum reading, was used for this purpose.

This deflection of one part of the slab caused certain stresses of compression and tension to be set up in the material itself. Concrete being weak in tension, the tensile stress is obviously the governing one. Hence it was necessary to measure the maximum tensile stress created by the impact. An instrument known as a graphic strain gage was used very successfully to measure these deformations. This instrument also was devised in the Bureau of Public Roads, and its construction and operation is described in "Engineering News-Record," March 22, 1923, in an article entitled "A new impact strain gage," by A. T. Goldbeck.





TOP.—THE IMPACT MACHINE.

BOTTOM.—CLOSE-UP OF IMPACT MACHINE AND SET-UP OF APPARATUS FOR THE EDGE TEST, SHOWING GRAPHIC STRAIN GAUGES IN TOP AND BOTTOM OF THE CONCRETE BASE, DEFLECTION DIAL, THERMOMETER IN BITUMINOUS MATERIAL, AND ACCELEROMETER MOUNTED ON SHELF BELOW AXLE.

In addition to the data thus obtained, it was necessary to know exactly the height of drop used each time. For this purpose a stylus connected directly to the truck wheel was used to trace a record on a paper which was carried on a drum. By determining the point at which the wheel comes in contact with the slab this total height of drop can be divided into the component parts of free fall, rubber deformation and slab deflection.

AUXILIARY TESTS.

In addition to the actual impact test on each slab, an auxiliary test was always made to determine the load supporting value of the subgrade. Also in the case of the concrete slabs, compression tests were run on the 6 by 12 inch test cylinders, previously mentioned, to determine the modulus of elasticity and the crushing strength of the concrete at the time of test.

The subgrade bearing value determination was made with a portable apparatus shown in the accompanying illustration. The method of test is to apply a constantly increasing unit load to a small circular bearing block scraped to intimate contact with the subgrade, and to measure the penetration of this foot into the soil under the load. This test is described in Public Roads, volume 4, No. 5, September, 1921. "Preliminary report on the Bates experimental road."

The determination of the modulus of elasticity by means of a compressometer is familiar to all and will not be described except to say that the instrument devised and built by the Bureau of Public Roads and described in American Society for Testing Materials Proceedings, 1923, "Slag as a concrete aggregate," by Raymond Harsch, gives excellent results and apparently is free from the lag so common in instruments of this type.

Typical modulus of elasticity curves for concrete of the two mixes used are shown in the accompanying diagram.

Table II.—*Average compressive strength of all test cylinders.*

Class of sections.	Compressive strength in pounds per square inch. 1:3:6 mix.	1:1½:3 mix.
Dry subgrade	1,420	4,180
Dry subgrade, rod-reinforced slabs	------	5,948
Wet subgrade	1,477	4,459

THE SUBGRADE AND ITS EFFECT ON SLAB RESISTANCE.

These slab tests have especially emphasized the important part the subgrade plays in the resistance of a road slab of any type. The rigid slabs on the wet subgrade showed roughly two-thirds of the resistance of duplicate slabs on the good subgrade.

The results of the subgrade determination varied somewhat, but it was nearly always possible to get two curves to check closely out of three or four tests, which is the number of tests usually made at each slab. The load-penetration curve was plotted for each test and these curves averaged for each subgrade. The three average curves grouped in the figure reproduced on page 10 show clearly the difference in bearing value of the three subgrades. There was considerable variation in moisture content of the samples taken and no relation could be found between moisture content and bearing value. The reason for this is thought to be primarily in the varying soil characteristics of the different samples due to the topographic location of the different slabs. No laboratory analysis was attempted on the many samples taken. Except to say that the moisture for the samples taken ran on the average from 5 to 10 per cent higher on the wet subgrade than on the dry, it is not thought worth while to present the data on these moisture tests.

BEHAVIOR OF THE CONCRETE SLABS.

It was considered that a rigid slab had failed when the strain gage record indicated the formation of the first crack. This was selected as a definite point of comparison for slabs of this type, but the behavior of the section beyond this point was also considered in comparing reinforced types.

It is not possible to derive an exact mathematical relation from the results of such tests as these, but it would seem from the examination of the most nearly comparable sections that the resistance of the slabs varies neither directly with the depth nor with the square of the depth, but as some power less than two. There are other factors present on which there are no data, such as the relation between bending and shearing stresses in different depths of slabs, which may be, and probably are, very important.

Impacts were applied at the corner and at the center of one side of each type of slab. There seems to be practically the same resistance at both points of loading in the plain concrete slabs. When there was steel present in sufficient amount and in the proper place to resist tension, the tests showed a corresponding increase in resistance.

The edge test invariably resulted in a transverse crack beginning with an incipient crack on the bottom of the slab directly under the wheel. This crack developed rapidly across the slab. Thin slabs punched out immediately following the formation of the crack. One 8-inch, 1:3:6 slab developed a longitudinal crack which divided the slab into quarters. It is probable in this case that the inertia of the heavy slab caused tension which exceeded the strength of the concrete.

The corner test caused a curved crack across the corner due to tension in the top fibers of the slab. The unit fiber deformation at failure was the same

Table III.—*Test data on rigid slabs.*

LAID ON WET SUBGRADE.

Slab No.	Construction: Concrete base: Thickness	Concrete base: Mix	Top course: Thickness	Top course: Material	Point of application of load	Maximum impact resisted	Maximum unit fiber deformation: Elastic	Maximum unit fiber deformation: At failure	Average modulus of elasticity at failure	Average crushing strength of 3 cylinders
	Inches		*Inches*			*Pounds*			*Pounds per sq. in.*	*Pounds per sq. in.*
222	6	1:3:6	1½	Sheet asphalt [1]	Edge	10,800	0.000230	0.000300	2,027,500	989
223	6	1:3:6	1½	do [1]	Corner	8,000	([2])	([2])	------	1,118
224	6	1:3:6	4	Bituminous concrete	Edge	8,000	([3])	([3])	------	2,086
225	6	1:3:6	4	do	Corner	8,000	([2])	([2])	------	1,738
226	6	1:3:6	2	do	Edge	8,000	([3])	([3])	------	1,141
227	6	1:3:6	2	do	Corner	8,000	([2])	([2])	------	901
228	4	1:3:6	2	Topeka	Edge	2,000	([4])	([4])	------	1,384
229	4	1:3:6	2	do	Corner	2,000	([5])	([5])	------	798
230	4	1:1½:3	2	do	Edge	([6])	------	------	------	3,365
231	4	1:1½:3	2	do	Corner	([6])	------	------	------	3,817
232	6	1:3:6	2	do	Edge	9,410	------	([7])	------	2,001
233	6	1:3:6	2	do	Corner	8,000	([2])	([2])	------	1,708
234	6	1:1½:3	2	do	Edge	11,850	.000306	.000324	4,330,000	4,268
235	6	1:1½:3	2	do	Corner	9,500	.000284	.000305	4,390,000	4,418
236	8	1:3:6	2	do	Edge	16,100	.000225	.000257	3,270,000	1,673
237	8	1:3:6	2	do	Corner	11,600	.000330	.000379	2,815,000	1,849
238	8	1:1½:3	2	do	Edge	25,250	.000242	.000267	4,685,000	5,100
239	8	1:1½:3	2	do	Corner	25,700	.000290	.000294	4,040,000	4,458
240	4	1:1½:3	------	------	Edge	([8])	.000155	.000208	4,450,000	4,350
241	4	1:1½:3	------	------	Corner	([8])	.000150	------	4,590,000	5,076
242	6	1:1½:3	------	------	Edge	11,650	.000272	.000291	4,200,000	4,480
243	6	1:1½:3	------	------	Corner	14,000	.000258	.000370	4,410,000	5,213
244	6	1:3:6	------	------	Edge	9,200	.000218	.000283	2,805,000	1,803
245	6	1:3:6	------	------	Corner	9,960	.000151	------	3,290,000	1,832
246	8	1:1½:3	------	------	Edge	27,100	.000292	.000302	4,778,000	4,857
247	8	1:1½:3	------	------	Corner	24,700	.000267	.000495	4,190,000	3,701
248	8	1:3:6	------	------	Edge	14,275	.000242	.000284	2,235,000	1,160
249	8	1:3:6	------	------	Corner	15,075	.000269	.000360	2,455,000	1,385

[1] Laid on 1½-inch binder course.
[2] Static load broke corner off.
[3] Static load cracked base.
[4] Static load caused new cracks; badly cracked in rolling.
[5] Static load caused 0.65 inch deflection; badly cracked in rolling.
[6] Too badly broken to test.
[7] Not obtained.
[8] Static load, 8,000.

TABLE III.—*Test data on rigid slabs*—Continued.

LAID ON WET SUBGRADE—Continued.

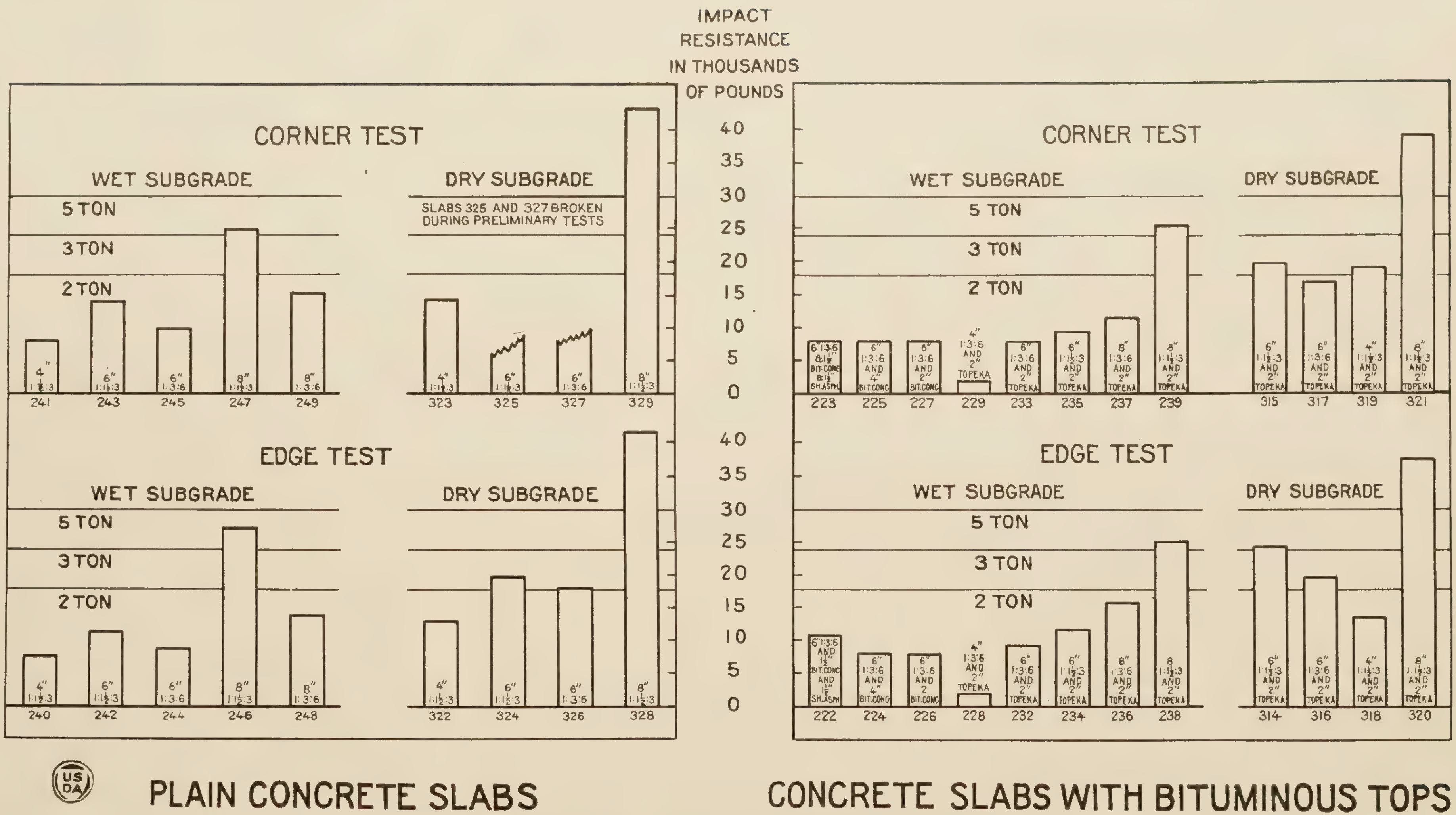
Slab No.	Construction of concrete slab.			Point of application of load.	Maximum impact resisted.	Maximum unit fiber deformation.		Average modulus of elasticity at failure.	Average crushing strength of 3 cylinders.
	Thickness.	Mix.	Reinforcing.			Elastic.	At failure.		
	Inches.				*Pounds.*			*Pounds per sq. in.*	*Pounds per sq. in.*
250	4	1:1½:3	1 layer No. 6 (0.21 per cent)	Edge	8,000		0.000310	4,270,000	4,400
251	4	1:1½:3	do	Corner	10,730	0.000265	.000307	4,125,000	4,330
252	4	1:1½:3	2 layers No. 6 (0.42 per cent)	Edge	7,550	.000203	.000365	4,250,000	4,243
253	4	1:1½:3	do	Corner	8,500	.000260	.000275	4,270,000	4,740
254	4	1:1½:3	2 layers No. 8 (0.66 per cent)	Edge	7,790	.000293	.000360	3,970,000	4,326
255	4	1:1½:3	do	Corner	10,260	.000286	.000309	4,125,000	4,163
256	4	1:1½:3	1 layer No. 10 (0.41 per cent)	Edge	7,025	.000278	.000301	4,422,000	4,643
257	4	1:1½:3	do	Corner	7,790	.000253	.000315	4,610,000	4,961
258	4	1:1½:3	2 layers No. 10 (0.82 per cent)	Edge	8,300	.000283	.000343	4,120,000	3,976
259	4	1:1½:3	do	Corner	10,950	.000281	.000317	4,650,000	4,184
260	6	1:1½:3	1 layer No. 6 (0.19 per cent)	Edge	16,600	.000267	.000298	4,255,000	4,733
261	6	1:1½:3	do	Corner	16,200	.000284		4,400,000	4,583
262	6	1:1½:3	2 layers No. 6 (0.38 per cent)	Edge	19,150	.000293	.000327	3,930,000	4,223
263	6	1:1½:3	do	Corner	21,500	.000298	.000314	4,390,000	4,200
264	6	1:1½:3	2 layers No. 8 (0.46 per cent)	Edge	17,700	.000309	.000315	3,940,000	4,410
265	6	1:1½:3	do	Corner	17,000	.000247	.000281	4,495,000	5,530
266	6	1:1½:3	2 layers No. 10 (0.58 per cent)	Edge	16,350	.000278	.000297	4,030,000	4,446
267	6	1:1½:3	do	Corner	14,560	.000308	.000414	4,595,000	4,572

LAID ON DRY SUBGRADE.

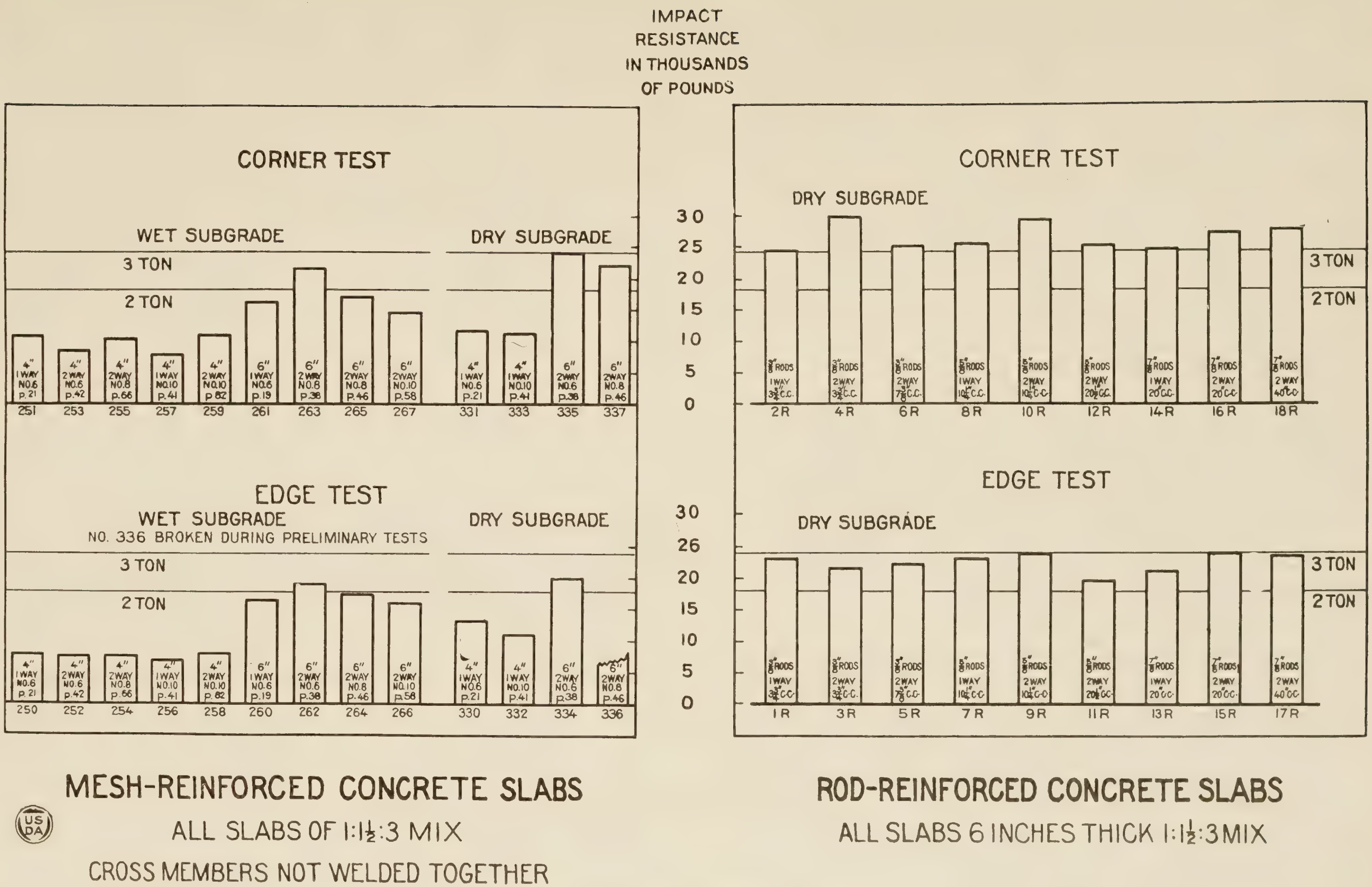
Slab No.	Construction.					Point of application of load.	Maximum impact resisted.	Maximum unit fiber deformation.		Average modulus of elasticity at failure.	Average crushing strength of 3 cylinders.
	Concrete.			Top course.							
	Thickness.	Mix.	Reinforcing	Thickness.	Material.			Elastic.	At failure.		
	Inches.			*Inches.*			*Pounds.*			*Pounds per sq. in.*	*Pounds per sq. in.*
314	6	1:1½:3		2	Modified Topeka.	Edge	24,500	0.000235	0.000282	(1)	
315	6	1:1½:3		2	do	Corner	19,950	.000298	.000371	(1)	
316	6	1:3 :6		2	do	Edge	19,800	.000296	.000319	3,340,000	2,325
317	6	1:3 :6		2	do	Corner	17,060	.000296	.000371	3,200,000	1,794
318	4	1:1½:3		2	do	do	13,650	.000272	.000340	3,300,000	3,212
319	4	1:1½:3		2	do	Edge	19,400	.000314	.000372	3,300,000	3,660
320	8	1:1½:3		2	do	do	37,800	.000295	.000315	3,660,000	3,940
321	8	1:1½:3		2	do	Corner	39,800	.000292	.000312	4,640,000	3,340
322	4	1:1½:3				Edge	13,300	(2)	.000353	4,750,000	4,488
323	4	1:1½:3				Corner	14,000	.000308	.000319	4,000,000	3,938
324	6	1:1½:3				Edge	20,000	.000271	.000297	4,330,000	4,698
325	(3)										5,446
326	6	1:3 :6				Edge	18,300	.000237	.000292	2,620,000	1,632
327	(3)										1,331
328	8	1:1½:3				Edge	41,500	.000337	.000395	3,620,000	3,334
329	8	1:1½:3				Corner	42,580	.000264	.000451	4,450,000	4,993
330	4	1:1½:3	1 layer No. 6 (0.21 per cent)			Edge	13,410	.000278	.000295	4,170,000	3,493
331	4	1:1½:3	do			Corner	11,600	.000280	.000312	4,500,000	4,709
332	4	1:1½:3	1 layer No. 10 (0.41 per cent)			Edge	11,250	.000243	.000332	4,850,000	4,183
333	4	1:1½:3	do			Corner	11,150	.000215	.000301	4,420,000	3,752
334	6	1:1½:3	2 layers No. 6 (0.38 per cent)			Edge	20,000	.000262	.000279	4,700,000	4,769
335	6	1:1½:3	do			Corner	23,700	.000256	(4)	4,710,000	4,806
336	(3)										4,626
337	6	1:1½:3	2 layers No. 8 (0.46 per cent)			Corner	21,800	.000244	.000277	4,330,000	3,861

Slab No.	Reinforcing of 6-inch 1:1½:3 concrete slabs.	Point of application of load.	Maximum impact resisted.	Maximum unit fiber deformation.		Average modulus of elasticity at failure.	Average crushing strength of 3 cylinders.
				Elastic.	At failure.		
			Pounds.			*Pounds per sq. in.*	*Pounds per sq. in.*
1-R	1 layer ⅜-inch rods 3¾ inches center to center	Edge	23,050	0.000271	0.000308	4,550,000	6,068
2-R	do	Corner	24,100	.000281	.000302	4,960,000	6,193
3-R	2 layers ⅜-inch rods 3¾ inches center to center	Edge	21,450	.000296	.000355	4,395,000	5,920
4-R	do	Corner	29,200	.000281	.000301	4,625,000	6,508
5-R	2 layers ⅜-inch rods 7⅜ inches center to center	Edge	22,000	.000286	.000348	4,765,000	5,548
6-R	do	Corner	24,700	.000247		4,950,000	5,857
7-R	1 layer ⅝-inch rods 10¼ inches center to center	Edge	22,930	.000228	.000308	4,510,000	6,427
8-R	do	Corner	24,900	.000273		5,000,000	6,635
9-R	2 layers ⅝-inch rods 10¼ inches center to center	Edge	23,600	.000267	.000304	4,630,000	5,701
10-R	do	Corner	28,650	.000277	.000308	4,835,000	5,833
11-R	2 layers ⅝-inch rods 20½ inches center to center	Edge	19,350	.000243	.000300	4,540,000	6,161
12-R	do	Corner	24,650	.000287		4,740,000	6,174
13-R	1 layer ⅞-inch rods 20 inches center to center	Edge	20,900	.000281	.000367	4,940,000	5,738
14-R	do	Corner	24,150	.000297	.000399	4,155,000	5,426
15-R	2 layers ⅞-inch rods 20 inches center to center	Edge	23,850	.000247	.000348	5,125,000	5,866
16-R	do	Corner	26,550	.000243	.000345	4,805,000	6,113
17-R	2 layers ⅞-inch rods 40 inches center to center	Edge	23,050	.000301	.000348	4,515,000	6,040
18-R	do	Corner	27,100	.000292	.000304	4,420,000	4,880

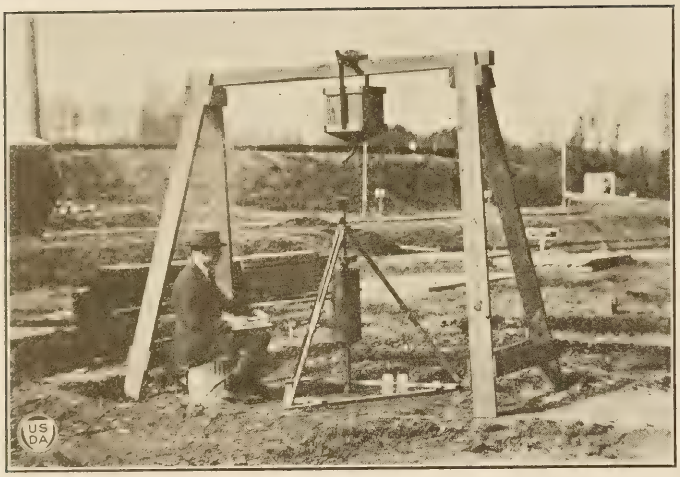
[1] No test cylinders. [2] Not obtained. [3] Broken during preliminary test last year. [4] Beyond gauge length.



Impact resistance of plain concrete slabs and concrete slabs with bituminous tops.



Impact resistance of mesh-reinforced and rod-reinforced concrete slabs

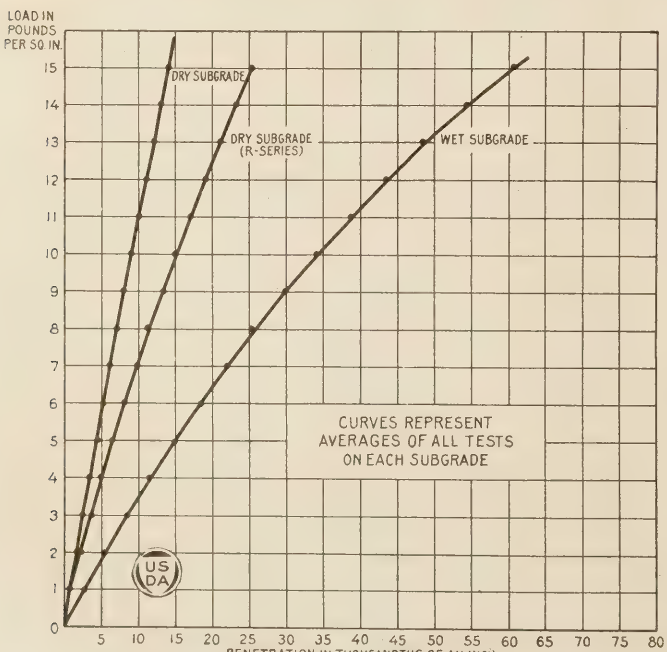


Subgrade bearing value determination. Shot from an overhead container falls at a constant rate into a drum supported by a small bearing block. The penetration of this block into the subgrade is measured by an Ames dial.

as that on the bottom of the slab in the edge test. The area broken off in the corner tests seems to depend on the condition of the subgrade, as it is noticeable that smaller areas are broken off where the subgrade is firm. It was found possible to break off a corner by an impact delivered at the quarter point of one edge; i. e., at a point 21 inches from the corner along one edge. This would seem to indicate that some corner breaks may start from impacts delivered along the edge which produce tension in the bottom of slab.

THE EFFECT OF REINFORCING.

A study of the data must inevitably lead to the conclusion that fabric reinforcing of the type used in these tests at or near the center of a road slab does not appreciably increase its resistance to impact. Observation at the time of test bears this out. In the percentages used in these test sections, no great additional strength was noticed after the formation of the first crack, and in no case did repeated applications of

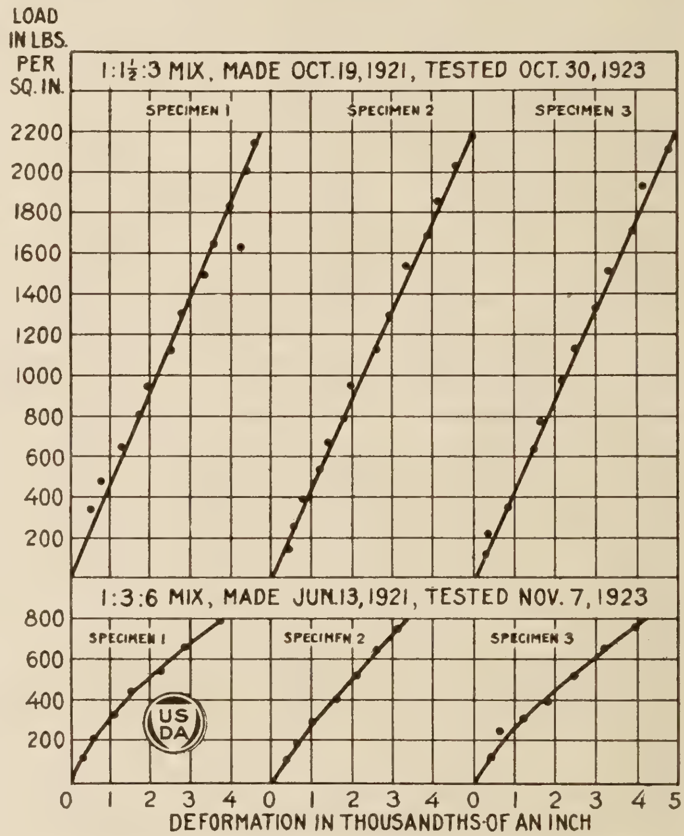


Load-penetration curves. Soil bearing value tests.

the same impact which caused failure fail to open up a crack into which water and mud could work and attack the steel.

Results of the tests on slabs reinforced with deformed bars show a definite increase in strength, particularly in the corner tests where the steel was in a better position to take tensile stress. The compression cylinders indicate a somewhat stronger concrete in this group of slabs for no known reason, the same care having been taken in placing all of the slabs. To offset this, however, the subgrade shows a lower bearing value than the other sections on the dry subgrade.

In the corner test the slabs having 1 per cent of steel show about 13 per cent more strength than the slabs having 0.5 per cent. A study of the behavior of the breaks after failure leads to the conclusion that, for a given percentage of steel, small rods closely spaced are more effective than large rods widely spaced.

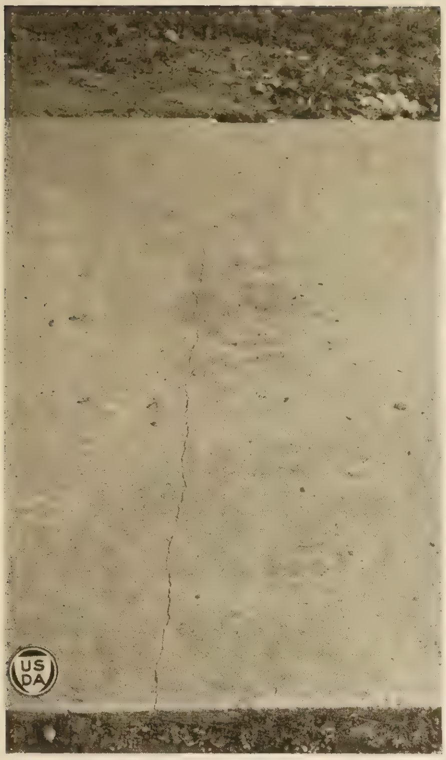


Typical modulus of elasticity curves obtained from 6 by 12 inch compression cylinders.

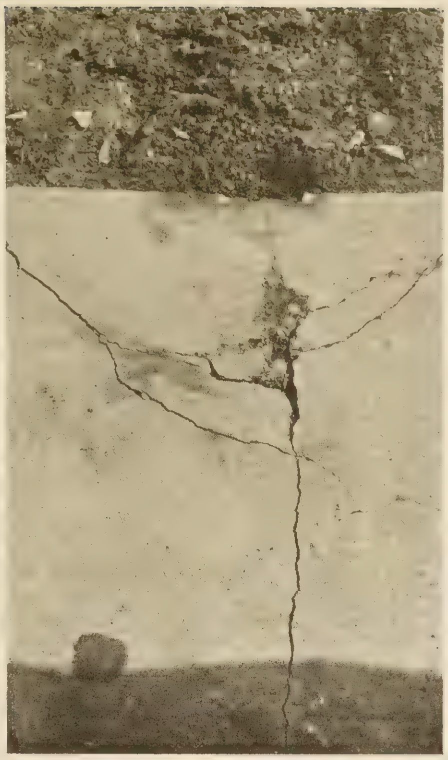
In the edge test there was little additional resistance to the formation of the first crack. This was to be expected in view of the fact that the steel was placed in the upper part of the slab. But a very marked resistance to further failure was apparent in all the slabs. In no case was it possible to develop the crack through to the top of the slab, although a complete transverse crack showed at the bottom. Additional very high impacts failed to break down this resistance. This was not true of the mesh-reinforced slabs.

LITTLE EVIDENCE OF CUSHIONING BY BITUMINOUS TOPS.

In examining the data with the idea of finding out to what extent bituminous tops on concrete cushion the impact of traffic, there are a number of facts to be borne in mind. Everyone is familiar with the springi-



Transverse crack, the result of impact on a 6-inch 1:1½:3 plain concrete slab.

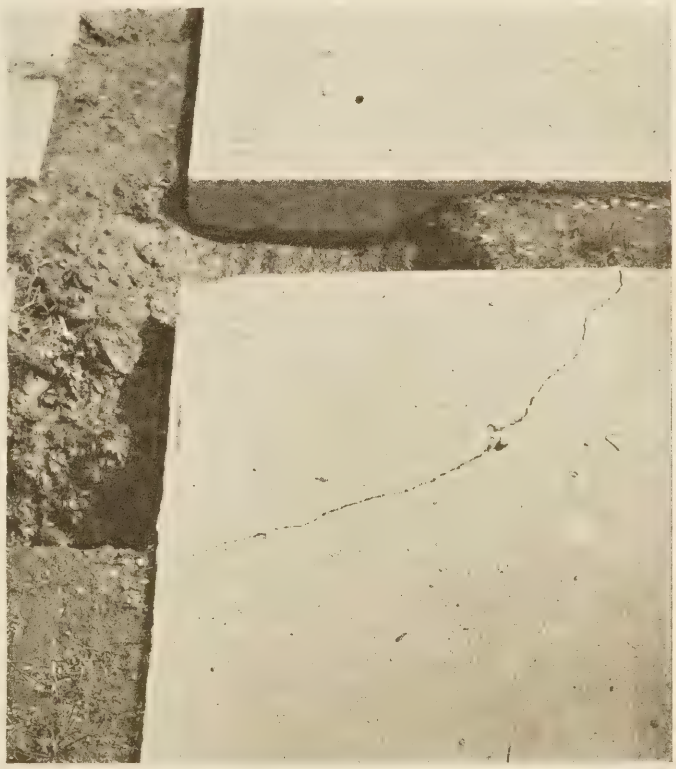


Transverse crack with corners broken off in a 4-inch, mesh-reinforced concrete slab.

Transverse and longitudinal crack resulting from impact on an 8-inch, 1:3:6 plain concrete slab.

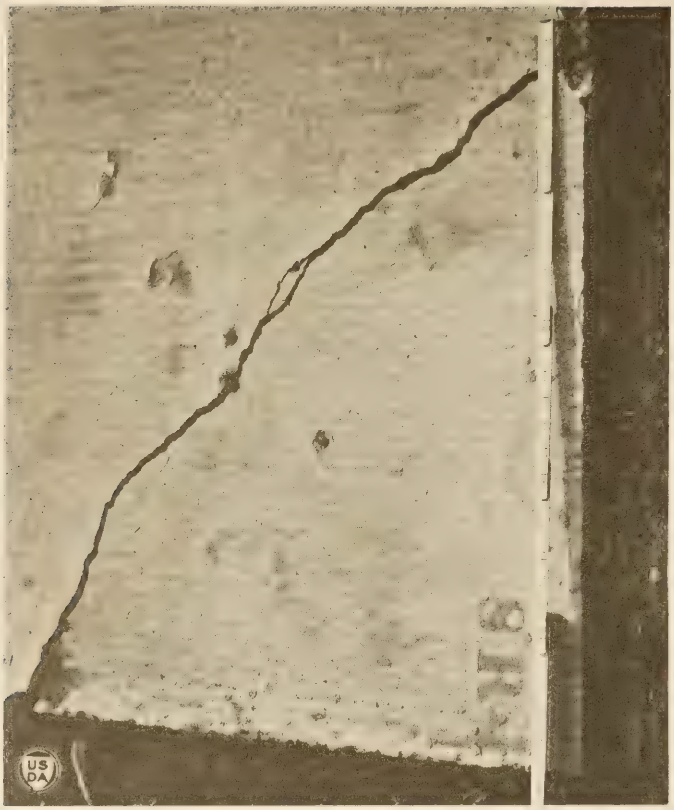
Typical failures in edge tests of concrete slabs laid on wet subgrade.

6-inch mesh-reinforced concrete slab.

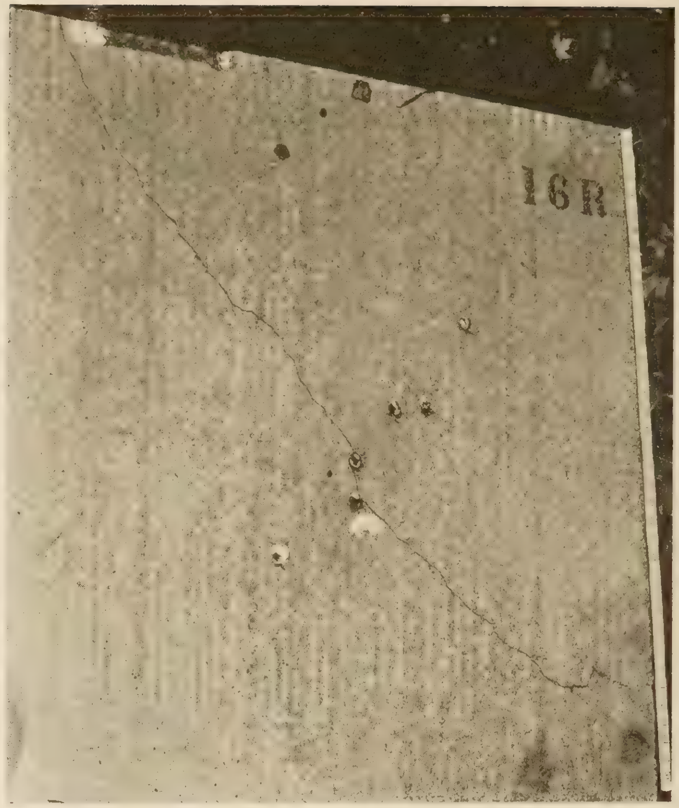


6-inch plain concrete slab.

Typical failures in corner tests of concrete slabs laid on wet subgrade.

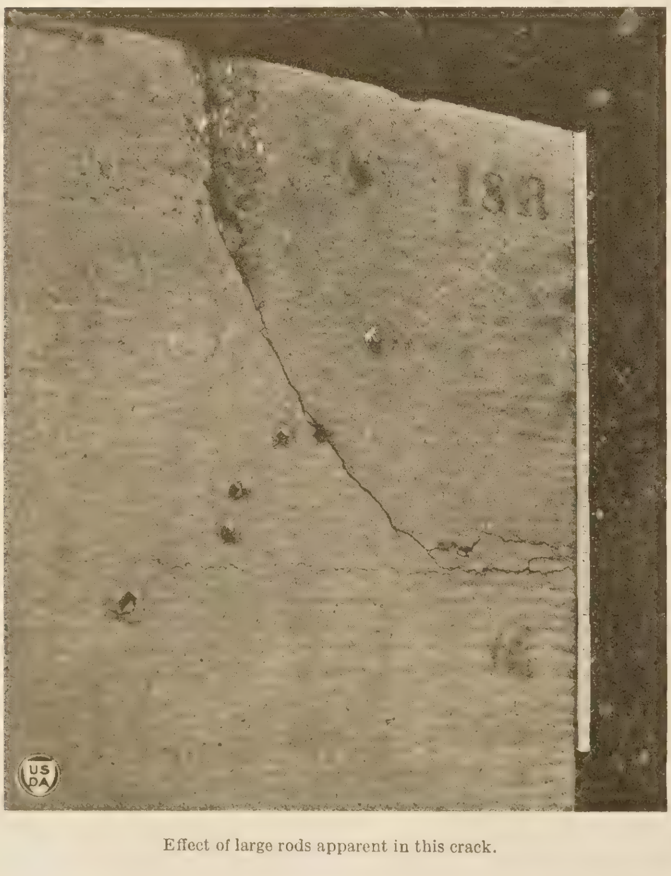


Low percentage of steel and one-way placing result in wide crack under additional impact.

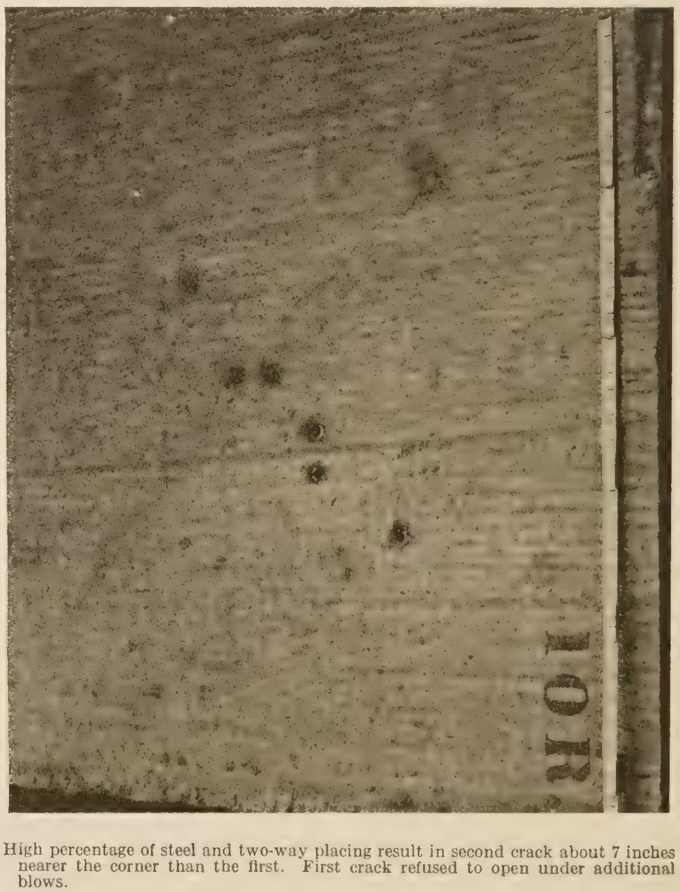


Effect of a larger percentage of steel—a small crack which does not open up under additional impact.

Typical failures of rod-reinforced sections in corner test.

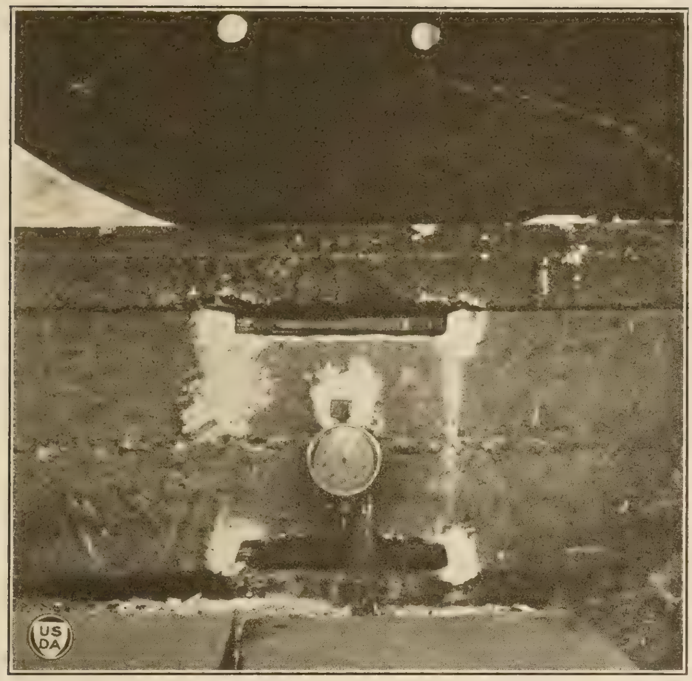


Effect of large rods apparent in this crack.



High percentage of steel and two-way placing result in second crack about 7 inches nearer the corner than the first. First crack refused to open under additional blows.

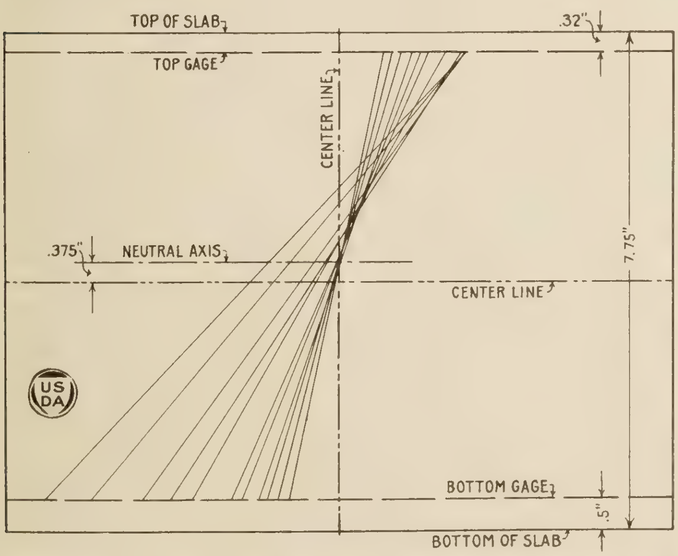
Typical failures of rod-reinforced sections in corner test.



Set-up of strain gauges and deflection dial for the edge test. Topeka top beginning to crack.

ness of an asphalt city pavement on a hot day, and it is easy to jump to the conclusion that such a surface acts as a cushion to the blows of traffic.

But even in this springy state, while undoubtedly the bituminous mixture yields readily to a steady pressure, it is doubtful if it moves appreciably under an impact whose duration is but a small fraction of a second. To cushion a wheel impact, something must act to bring the wheel slowly to rest; in this case the asphalt top must move and move considerably. Observations during the impact tests show that it does move, but under a single blow its movement is very slight indeed. The results of all comparable slabs with and without asphalt tops (2-inch modified Topeka) show little evidence of cushioning due to these tops.



Determination of neutral axis from strain gauge measurement on concrete slabs with bituminous tops. The neutral axis remains fixed until the lower fibers begin to fail.

The temperature is an extremely important factor in the behavior of bituminous mixtures. The tests herein described were made during the summer months and the temperatures of the asphalt varied from 25° to 32° C. (77° to 90° F.) Undoubtedly at higher temperatures more movement would take place in the material under a wheel impact.

Table IV shows the results from which these conclusions were drawn.

TABLE IV.—*Data on cushioning of bituminous tops.*

Concrete.		Plain.		With 2-inch Topeka top.	
Mix.	Thickness.	Height of drop.	Impact of 2-ton truck wheel.	Height of drop.	Impact of 2-ton truck wheel.
Dry subgrade:	*Inches.*	*Inches.*	*Pounds.*	*Inches.*	*Pounds.*
1 : 1½ : 3	4	0.97	11,440	0.95	12,060
1 : 3 : 6	6	.54	18,300	.62	19,800
1 : 1½ : 3	6	.68	20,000	.60	24,500
1 : 1½ : 3	8	1.15	41,500	1.23	37,800
Wet subgrade:					
1 : 1½ : 3	4	(1)	(1)	----	----
1 : 3 : 6	6	.48	9,200	.47	9,460
1 : 1½ : 3	6	1.06	11,600	1.18	11,330
1 : 3 : 6	8	.40	8,660	.46	8,975
1 : 1½ : 3	8	1.53	27,100	1.92	25,250

[1] Failed under static load.

To draw an absolute conclusion regarding cushioning, every condition of subgrade, sprung weight, unsprung weight, height of drop, etc., should be identical. With these conditions constant, a top which acts as a cushion should show a lower impact force for a given height of drop. The slabs listed in the table are compared in this manner, and with one exception they show no evidence of this effect. The 8-inch slabs of the 1 : 1½ : 3 mix show indications of such an action toward the end of the test where very heavy impacts were being applied. At the impact which broke the 4-inch and 6-inch slabs no cushioning is apparent.

It is realized that perfect conditions for comparison did not obtain in the case of these tests, especially in the matter of subgrade support. They more nearly duplicate road conditions, however, and for this reason should be more valuable than some laboratory tests which do not in any way compare with truck-wheel impact.

Set-up for the corner test. Strain gauges on top of slab are for determination of maximum tensile stress. Those in edge of slab locate the neutral plane.

EFFECT OF BITUMINOUS TOPS ON SLAB STRENGTH.

The resistance of the concrete slabs of the different mixes and thickness is not, in general, increased by the addition of a bituminous top of the thickness used in these tests, except possibly in the case of the 4-inch and 6-inch bases on the dry subgrade. Several showed distinctly less resistance, but it should be noted that these were slabs laid on the wet subgrade and in several cases there was evidence of deterioration in the concrete under the bituminous layer. Evaporation of moisture from the concrete was prevented and this may have caused the weakened condition of these bases. The 1 : 3 : 6 mix seemed to be affected to a greater degree than the 1 : $1\frac{1}{2}$: 3 mix.

There was very little bond between the concrete bases and the bituminous surfaces of any of the types used. Certainly there was not enough to resist appreciable horizontal shearing stresses. These observations were borne out by the strain gage readings in the edge test, which showed no raising of the neutral plane of the slab when a bituminous top was added. The average of all of the edge tests on these slabs on the dry subgrade showed the neutral plane to be 0.37 inch above the horizontal center plane of the slab. The same data for the concrete slabs without bituminous tops showed an average measurement of 0.39 inch above the horizontal center plane. The fact that all the slabs showed this plane to be above center may be due to a lesser density of the concrete next to the subgrade.

Topeka tops proved to be extremely tough and resistant to cracking, more so than the sheet asphalt with binder course. Even after the failure of the concrete bases, the bituminous layer bridged the crack and withstood the impact, materially reducing the destructive effect of the succeeding blows. On the dry subgrade, where the foundation support was good, these Topeka tops withstood very severe punishment with little deformation or cracking.

MOTOR VEHICLE REGISTRATION 15,092,177.

$225,784,932 AMOUNT OF ANNUAL LICENSE FEES AND GASOLINE TAXES.

By ANDREW P. ANDERSON, Highway Engineer, U. S. Bureau of Public Roads.

THE YEAR 1923 has shown a truly remarkable increase in the number of motor vehicles. A total of 15,092,177 passenger cars, motor trucks, and commercial vehicles were registered in the 48 States and District of Columbia during the registration year 1923. This is an actual increase over 1922 of 2,853,802 registrations, 408,136 more cars than the total number registered in 1915, or 1,078,722 more than the greatest previous increase recorded during one year.

There are now approximately 2 motor vehicles for every 15 persons of our total population, and if the increase during the present year should be as great as during the past, we shall have at the end of the year 1 motor vehicle for every 6 persons of our total estimated population—enough to transport our entire population at one time should the necessity arise.

The statistics of motor-vehicle registrations read more like a tale from Baron Munchausen or the Arabian Nights than prosaic records of actual facts. In 1913, the earliest year for which fairly reliable data are available, the total number of vehicles registered was only 1,258,062, or approximately one-twelfth of the present number. In 1919 the registrations had increased to 7,565,446, or almost exactly one-half of the total for 1923. This rate of increase obviously can not continue indefinitely, but the records of the past give no clue as to when or how it will cease.

Owners of these motor vehicles are insistent in their demand for improved roads, and they are apparently contributing substantially to the funds available for road work, especially for the maintenance of State highways. Total gross receipts from registration fees, together with the licenses of drivers, chauffeurs, etc., which in 1913 amounted to only $8,192,253, in 1923 amounted to $188,970,992.24. Thus, while the number of motor vehicle registrations increased only 12 times during the 10-year period, the funds so collected increased 23 times.

Practically the whole amount of the license fees collected, after deducting the sums required to pay the cost of registration, is now devoted to road work or to the financing of debts incurred for road construction, and by far the greater part of these funds is expended by or under the supervision of the State highway departments. Of the total of $188,970,992.24 collected during 1923, $153,226,636.16 has been or will be applied to road work conducted by or under the supervision of the State highway departments, although in a few States this supervision or control is not as complete as it should be.

AVERAGE MOTOR TRUCK FEE MORE THAN TWICE THAT OF AVERAGE PASSENGER CAR.

Returns from 29 States in which the records permit the segregation of fees paid for motor trucks from those paid for passenger cars show that the fee paid for the average truck is more than twice as great as the average fee paid per passenger car. In these 29 States a total of $24,020,784.89 was paid in fees for 1,103,076 motor trucks and only $91,031,927.06 for 8,671,635 passenger cars.

In addition to the direct fees paid by the motor-vehicle owner or operator, he also pays a large amount in indirect fees or taxes. In most States motor vehicles are taxed as personal property. Many cities levy wheel taxes or additional registration fees. The Federal Government collects an excise tax of 5 per cent of the manufacturer's sale price on all passenger cars, parts, tires, and accessories and 3 per cent on the sale price of motor trucks. And over and above all these taxes the majority of the States now tax gasoline or motor fuel. This form of tax has proved to be most popular with the State legislatures. First adopted by the States of Oregon, New Mexico, and Colorado in 1919, this form of taxation is now in force in 35 States, the tax ranging from 1 to 4 cents

TABLE I.—*Motor vehicle registration, licenses, and revenues, registration year 1923.*

State.	Grand total motor cars.	Private passenger cars.	Motor trucks.	Taxis, busses, and cars for hire.[1]	Motor cycles.	Registration fees, licenses, and permits.		Amount of registration fees paid.		Total registration, 1922.	Per cent increase during 1923.
						Total gross receipts.	Amount applicable to highway work by or under supervision of State highway department.	Private passenger cars.	Motor trucks.		
Alabama	126, 642	109, 535	13, 845	3, 262	599	$1, 541, 017. 56	$1, 204, 449. 02			90, 052	40. 4
Arizona	49, 175	42, 176	6, 565	434	392	281, 670. 75	281, 670. 75			38, 034	29. 3
Arkansas	113, 300	102, 000	11, 300		300	1, 435, 090. 00	430, 527. 12	$1, 224, 000. 00	$192, 100. 00	84, 596	33. 9
California	1, 100, 283	1, 056, 756	43, 527		14, 694	10, 608, 544. 00	4, 906, 015. 00	9, 081, 836. 00	814, 138. 00	861, 807	27. 7
Colorado	188, 956	175, 669	13, 287	(2)	2, 473	1, 126, 218. 55	534, 953. 81	898, 666. 40	153, 741. 57	162, 328	16. 4
Connecticut	181, 748	148, 791	29, 140	3, 817	4, 450	4, 329, 432. 16	4, 329, 432. 16	2, 302, 154. 23	956, 368. 93	152, 977	18. 8
Delaware	29, 977	24, 709	5, 268		467	516, 209. 00	516, 209. 00	287, 950. 00	108, 379. 00	24, 560	22. 1
District of Columbia[3]	74, 811	[3] 65, 681	[3] 7, 187	[3] 1, 943	1, 772	357, 918. 00				52, 792	41. 7
Florida	151, 990	125, 140	23, 530	3, 320	975	1, 963, 065. 99	1, 394, 528. 58			116, 170	30. 8
Georgia	173, 889	151, 325	22, 469	95	1, 011	2, 156, 406. 08	2, 095, 762. 60	1, 756, 219. 20	344, 831. 04	143, 423	21. 2
Idaho	62, 379	57, 200	5, 179		655	914, 014. 58	229, 840. 14	807, 678. 15	87, 309. 43	53, 874	15. 8
Illinois	969, 331	847, 005	122, 326		7, 611	9, 653, 796. 04	9, 653, 796. 04	7, 132, 472. 16	1, 820, 379. 48	781, 974	23. 9
Indiana	583, 342	510, 114	73, 228		6, 042	3, 693, 715. 00	3, 492, 498. 00	2, 651, 084. 00	794, 003. 00	469, 939	24. 1
Iowa	571, 061	534, 796	36, 265		3, 044	8, 827, 062. 99	[4] 8, 000, 000. 00			500, 158	14. 2
Kansas	375, 594	349, 038	26, 556	(5)	1, 950	3, 435, 606. 00	[6] 1, 750, 000. 00			327, 194	14. 8
Kentucky	198, 377	177, 834	20, 543		844	2, 678, 732. 89	2, 678, 732. 89			154, 021	28. 8
Louisiana	136, 622	116, 003	20, 619		400	2, 191, 240. 81	2, 191, 240. 81	1, 800, 186. 81	336, 000. 00	102, 284	33. 6
Maine	108, 609	90, 177	15, 614	2, 818	1, 400	1, 660, 268. 17	1, 474, 383. 39			92, 539	17. 4
Maryland	169, 351	153, 661	11, 609	4, 081	4, 846	3, 536, 955. 20	3, 183, 259. 68	2, 230, 333. 05	461, 539. 95	165, 624	[18] 24. 0
Massachusetts	481, 150	407, 645	73, 505		11, 033	6, 989, 633. 25	6, 639, 155. 42	4, 314, 529. 50	1, 117, 834. 00	385, 231	24. 8
Michigan	730, 658	657, 148	72, 000	1, 510	4, 165	10, 500, 786. 05	4, 741, 624. 91	8, 135, 757. 89	[7] 1, 225, 958. 00	578, 210	26. 4
Minnesota	448, 187	399, 404	48, 783		3, 220	7, 316, 772. 03	7, 316, 772. 03	6, 212, 601. 93	959, 495. 66	380, 557	17. 8
Mississippi	104, 286	93, 846	10, 440	(2)	114	1, 077, 616. 22	580, 852. 12			77, 571	34. 4
Missouri	476, 598	430, 340	46, 258		2, 570	4, 016, 383. 60	[8] 4, 016, 383. 60			392, 523	21. 5
Montana	73, 828	65, 449	8, 379		374	729, 621. 50	[9] 73, 325. 64	604, 663. 75	93, 162. 75	62, 650	17. 8
Nebraska	286, 053	259, 382	26, 671		1, 608	3, 353, 175. 32	2, 932, 242. 63	2, 754, 430. 61	498, 750. 99	256, 654	11. 4
Nevada	15, 699	13, 699	2, 000		112	153, 888. 10	[10] 144, 992. 15	119, 798. 10	30, 000. 00	12, 116	29. 6
New Hampshire	59, 604	52, 608	6, 996	(5)	1, 987	1, 571, 326. 96	1, 464, 096. 88			48, 406	23. 2
New Jersey	430, 958	330, 552	89, 105	11, 301	8, 811	7, 653, 780. 37	7, 515, 116. 03	3, 069, 466. 75	2, 407, 423. 50	342, 286	25. 9
New Mexico	32, 032	29, 032	3, 000		215	295, 000. 00	280, 250. 00	251, 995. 00	36, 000. 00	25, 473	25. 7
New York	1, 204, 213	962, 681	203, 846	37, 686	22, 153	19, 862, 441. 52	14, 896, 831. 14	11, 689, 802. 97	5, 391, 418. 25	1, 002, 293	20. 1
North Carolina[11]	246, 812	225, 488	21, 324	(2)	1, 300	3, 728, 044. 72	[4] 3, 700, 000. 00			182, 550	35. 2
North Dakota	109, 266	105, 958	3, 287	21	645	760, 852. 45	760, 444. 45			99, 052	10. 3
Ohio	1, 069, 100	927, 200	141, 900		15, 000	9, 662, 370. 29	4, 832, 962. 25			858, 716	24. 5
Oklahoma	307, 000	288, 424	18, 576	(2)	823	3, 217, 770. 84	[12] 2, 895, 000. 00			249, 659	23. 0
Oregon	165, 962	[13] 152, 135	12, 987	840	3, 140	4, 069, 609. 40	[14] 2, 924, 707. 05			134, 125	23. 7
Pennsylvania	1, 043, 770	[15] 969, 361	74, 409		19, 220	15, 844, 303. 80	15, 844, 303. 80	9, 944, 691. 80	3, 410, 031. 50	829, 737	25. 8
Rhode Island	76, 312	60, 620	13, 930	1, 762	1, 575	1, 286, 659. 47	1, 196, 909. 47	727, 704. 72	275, 240. 27	66, 083	15. 5
South Carolina	127, 467	115, 892	11, 575		547	902, 608. 69	722, 086. 95	728, 644. 01	153, 593. 69	95, 239	33. 8
South Dakota	131, 700	121, 164	10, 536		471	1, 130, 959. 27	1, 055, 175. 80			125, 241	5. 2
Tennessee	173, 365	154, 181	19, 184		751	2, 049, 653. 27	2, 028, 806. 14			135, 716	27. 8
Texas	688, 233	[16] 688, 233	(2)		3, 346	5, 441, 508. 59	2, 368, 569. 43			526, 238	30. 8
Utah	59, 525	51, 625	7, 900		766	430, 104. 72	[14] 430, 104. 72			49, 164	21. 1
Vermont	52, 776	49, 420	3, 356		839	938, 860. 30	860, 803. 03	674, 868. 63	83, 394. 50	43, 881	20. 2
Virginia	218, 896	187, 977	30, 919		1, 813	3, 200, 161. 66	3, 200, 161. 66	2, 422, 993. 72	482, 670. 25	168, 000	30. 3
Washington	258, 264	218, 580	37, 100	2, 584	3, 560	3, 898, 597. 77	3, 741, 167. 81	2, 726, 121. 45	843, 041. 92	210, 716	22. 6
West Virginia	157, 924	143, 548	[17] 7, 456	6, 920	1, 353	2, 608, 508. 37	[8] 2, 608, 508. 37	1, 940, 093. 23	229, 157. 66	112, 763	40. 0
Wisconsin	457, 271	422, 718	34, 553	(2)	5, 645	4, 958, 933. 55	4, 693, 887. 30	4, 227, 180. 00	625, 619. 55	382, 542	19. 5
Wyoming	39, 831	35, 294	4, 537	(2)	291	414, 096. 39	[14] 414, 096. 39	314, 003. 00	89, 202. 00	30, 637	30. 1
Total	15, 092, 177	13, 457, 214	1, 552, 569	82, 394	171, 372	188, 970, 992. 24	153, 226, 636. 16	91, 031, 927. 06	24, 020, 784. 89	12, 238, 375	23. 6

[1] Where no data are given these vehicles are not registered as a separate class but included with passenger cars or trucks.
[2] Included with passenger cars.
[3] Includes re-registrations, but does not include nonresident registrations.
[4] Approximate.
[5] Included with trucks.
[6] Approximate amount available for State-aid road work.
[7] Includes receipts from taxicabs, motor busses, and cars for hire.
[8] For State highway work and financing State highway bonds.
[9] State's share for period Jan. 1 to Apr. 1 when new law becomes effective.
[10] Includes $48,115 used to finance State highway bonds.
[11] All data for the State of North Carolina are for the first 6 months of the registration year, which begins on July 1.
[12] To be expended by counties under general regulation made by State highway department.
[13] Includes ambulances and commercial cars under 1-ton capacity.
[14] To finance State highway bonds.
[15] Includes 88,650 commercial vehicles having a chassis weight of less than 2,000 pounds.
[16] Includes motor trucks.
[17] Solid-tire vehicles only.
[18] Nonresident registrations included in both years for this computation.

per gallon. In Massachusetts legislation providing for a tax of 2 cents per gallon has been passed, but is inoperative pending a referendum at the general election next November. In Minnesota provision has been made to submit to the voters at the next general election a constitutional amendment permitting such a tax to be levied.

The total gross receipts from gasoline taxes amounted to $36,813,939.61 during the calendar year 1923. Of this total, $21,528,559.18 is applicable to highway work conducted by or under the direct supervision of the State highway departments. Only one State, North Dakota, devotes no part of the revenue from this tax to highway work, and only two States, Alabama and Pennsylvania, place no part of these revenues under the direct control of the State highway department.

In compiling the statistics the registration year has been used as the basis rather than the calendar year. In most States the registration year coincides with the calendar year and in only one State, North Carolina, does the registration year differ very widely from the calendar year. In all cases where the registration year ends later than January 31 the registration data given are for the period from the beginning of the registration year to the close of the calendar year 1923. It is believed that this method serves to give the most reliable information as to the actual number of cars in use.

Tables I to IV, inclusive, show in more detail the statistics of motor-vehicle registration, revenues, and gasoline taxes for the year 1923 and also comparative data as to registrations and gross receipts for each of the years 1913 to 1923, inclusive.

TABLE II.—*Summary of combined passenger car and motor truck registrations for years 1913 to 1923, inclusive.*

State.	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
Alabama	5,300	8,672	11,634	21,636	32,873	46,171	58,898	74,637	82,366	90,052	126,642
Arizona	3,613	5,040	7,753	12,300	19,890	23,905	28,979	34,601	35,611	38,034	49,175
Arkansas	3,583	5,642	8,021	15,000	28,693	41,458	49,450	59,082	67,408	84,596	113,300
California	[1] 100,000	123,504	163,797	232,440	306,916	407,761	477,450	583,623	680,614	861,807	1,100,283
Colorado	13,000	17,756	28,894	43,296	87,460	83,244	104,865	129,255	145,739	162,328	188,956
Connecticut	23,200	27,786	41,121	56,048	74,645	86,067	102,410	119,134	134,141	152,977	181,748
Delaware	2,440	3,050	5,052	7,102	10,700	12,955	16,152	18,300	21,413	24,560	29,977
District of Columbia	4,000	4,833	8,009	13,118	15,493	30,490	35,400	34,161	40,625	52,792	[2] 74,811
Florida	[3] 3,000	[3] 3,368	[3] 10,850	20,718	[3] 27,000	54,186	55,400	73,914	97,957	116,170	151,990
Georgia	[3] 20,000	20,915	25,000	46,025	70,324	104,676	137,000	146,000	131,976	143,423	173,889
Idaho	2,113	3,346	7,071	12,999	24,731	32,289	42,220	50,861	51,294	53,874	62,379
Illinois	94,656	131,140	180,832	248,429	340,292	389,620	478,438	568,924	663,348	781,974	969,331
Indiana	45,000	66,500	96,915	139,065	192,194	227,160	227,255	333,067	400,342	469,939	583,342
Iowa	70,299	106,087	145,109	198,587	254,462	278,313	364,043	437,378	461,084	500,158	571,061
Kansas	34,550	49,374	72,520	112,122	159,343	189,163	228,600	294,159	289,539	327,194	375,594
Kentucky	7,210	11,766	19,500	31,500	47,420	65,884	90,008	112,683	126,802	154,021	198,377
Louisiana	[1] 10,000	[1] 12,000	11,380	17,000	28,394	40,000	51,000	73,000	77,885	102,284	136,622
Maine	11,022	15,700	21,545	30,972	41,499	44,572	53,425	62,907	77,527	92,539	108,609
Maryland	14,217	20,213	31,047	44,245	60,943	74,666	95,634	102,841	136,249	165,624	169,351
Massachusetts	62,660	77,246	102,633	136,809	174,274	193,497	247,182	274,498	360,732	385,231	481,150
Michigan	54,366	76,389	114,845	160,052	247,006	262,125	325,813	412,717	476,452	578,210	730,658
Minnesota	46,000	67,862	93,269	[4] 46,000	[5] 54,000	204,458	259,741	324,166	323,475	380,557	448,187
Mississippi	3,850	5,694	9,669	25,000	36,600	48,400	59,000	68,486	65,039	77,571	104,286
Missouri	38,140	54,468	76,462	103,587	147,528	188,040	244,363	297,008	346,437	392,523	476,598
Montana	5,916	10,200	14,540	25,105	42,749	51,053	59,324	60,650	58,785	62,650	73,828
Nebraska	13,411	16,385	59,000	101,200	148,101	173,374	200,000	219,000	238,704	256,654	286,053
Nevada	1,091	1,487	2,009	4,919	7,160	8,159	9,305	10,464	10,821	12,116	15,699
New Hampshire	8,237	9,571	13,449	17,508	22,267	24,817	31,625	34,680	42,039	48,406	59,604
New Jersey	51,360	62,961	81,848	109,414	141,918	155,519	190,873	227,737	272,994	342,286	430,958
New Mexico	1,898	3,090	5,100	8,228	14,086	17,647	18,082	22,100	22,559	25,473	32,032
New York	134,495	168,223	255,242	314,222	406,016	459,288	566,511	676,205	812,031	1,002,293	1,204,213
North Carolina	10,000	14,677	21,000	33,904	55,950	72,313	109,017	140,860	148,627	182,550	246,812
North Dakota	15,187	17,347	24,908	40,446	62,993	71,678	82,885	90,840	92,644	99,052	109,266
Ohio	86,156	122,504	181,332	252,431	346,772	412,775	511,031	621,390	720,634	858,716	1,069,100
Oklahoma	[3] 3,000	13,500	25,032	52,718	100,199	121,500	144,500	212,880	221,300	249,659	307,000
Oregon	13,975	16,447	23,585	33,917	48,632	63,324	83,332	103,790	118,198	134,125	165,962
Pennsylvania	80,178	112,854	160,137	230,578	325,153	394,186	482,117	570,164	689,589	829,737	1,043,770
Rhode Island	10,295	12,331	16,362	21,406	37,046	36,218	44,833	50,477	54,608	66,083	76,312
South Carolina	10,000	14,000	15,000	[1] 25,000	38,332	55,492	70,143	93,843	89,836	95,239	127,467
South Dakota	14,457	20,929	28,724	44,271	67,158	90,521	104,628	120,395	119,274	125,241	131,700
Tennessee	[1] 10,000	[6] 19,769	[7] 7,618	[1] 30,000	[1] 48,000	[1] 63,000	80,422	101,852	117,025	135,716	173,365
Texas	[1] 32,000	[1] 40,000	[1] 40,000	[1] 125,000	192,961	251,118	331,310	427,693	467,616	526,238	688,233
Utah	4,000	2,253	9,177	13,507	24,076	32,273	35,236	42,616	47,485	49,164	59,525
Vermont	5,913	8,475	11,499	15,671	21,633	22,553	26,807	31,625	37,265	43,881	52,776
Virginia	9,022	13,984	21,357	35,426	55,661	72,228	94,100	115,470	139,200	168,000	218,896
Washington	24,178	30,253	38,823	60,734	91,337	117,278	148,775	173,920	185,359	210,716	258,264
West Virginia	5,144	6,159	13,279	20,571	31,300	38,750	50,203	80,664	93,940	112,763	157,924
Wisconsin	34,346	53,161	79,741	115,645	158,637	196,253	236,290	293,298	341,841	382,542	457,271
Wyoming	1,584	2,428	3,976	7,125	12,523	16,200	21,371	23.926	26,866	30,637	39,831
Total	1,258,062	1,711,339	2,445,666	3,512,996	4,983,340	6,146,617	7,565,446	9,231,941	10,463,295	12,238,375	15,092,177

[1] Estimated.
[2] Includes reregistrations, but does not include nonresident registrations.
[3] State registrations only.
[4] Cars registered during 1916 only; total in State, approximately 138,000.
[5] Cars registered during 1917 only; total, approximately 160,000.
[6] Total cumulative registrations; annual registration not required.
[7] Cars registered during 1915 only; total, approximately 26,000

TABLE III.—*Summary of total gross receipts from motor vehicle registration fees, licenses, and permits, etc., for years 1913 to 1923.*

States.	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923
Alabama	$83, 000	$113, 202	$180, 744	$203, 655	$217, 700	$470, 274	$541, 348. 70	$835, 178. 00	$1, 147, 265. 00	[1] $1, 262, 800. 00	$1, 541, 017. 56
Arizona	27, 545	34, 077	45, 579	73, 000	117, 643	142, 288	164, 755. 68	192, 368. 92	195, 969. 75	216, 598. 26	281, 670. 75
Arkansas	17, 411	56, 420	80, 551	150, 000	205, 176	410, 649	500, 970. 00	591, 464. 50	856, 543. 60	1, 030, 196. 60	1, 435, 090. 00
California	75, 000	1, 338, 785	2, 027, 432	2, 192, 699	2, 846, 030	3, 524, 036	4, 468, 721. 67	5, 714, 717. 40	6, 834, 089. 52	8, 384, 606. 40	10, 608, 544. 00
Colorado	60, 833	80, 047	120, 801	197, 795	296, 808	379, 559	490, 432. 31	819, 872. 74	906, 059. 27	991, 677. 22	1, 126, 218. 55
Connecticut	316, 667	406, 623	536, 970	768, 728	1, 080, 757	1, 285, 164	1, 516, 136. 91	1, 852, 591. 00	2, 129, 861. 12	3, 567, 744. 84	4, 329, 432. 16
Delaware	24, 735	35, 672	55, 596	85, 249	133, 883	232, 449	286, 333. 00	329, 980. 00	375, 469. 00	426, 377. 00	516, 209. 00
District of Columbia	13, 228	20, 147	29, 396	47, 624	55, 928	220, 753	274, 184. 00	266, 285. 00	209, 583. 00	353, 726. 50	357, 918. 00
Florida	[2] 6, 000	[2] 6, 736	60, 000	127, 176	[3] 170, 000	345, 775	401, 317. 40	554, 695. 14	734, 845. 50	1, 538, 342. 26	1, 963, 065. 99
Georgia	12, 000	104, 575	125, 000	154, 735	229, 653	331, 816	429, 848. 00	1, 919, 338. 92	1, 705, 941. 24	1, 830, 047. 61	2, 156, 406. 08
Idaho	35, 160	58, 580	121, 259	213, 758	412, 641	576, 555	729, 702. 94	882, 034. 51	841, 212. 93	812, 943. 72	914, 014. 58
Illinois	507, 629	699, 725	924, 906	1, 236, 566	1, 588, 835	2, 764, 330	3, 262, 714. 00	5, 915, 700. 17	6, 803, 556. 21	7, 882, 482. 02	9, 653, 796. 04
Indiana	150, 345	432, 309	587, 318	817, 285	1, 096, 159	1, 293, 128	1, 558, 740. 50	2, 029, 694. 00	2, 422, 227. 00	2, 999, 588. 50	3, 693, 715. 00
Iowa	787, 411	1, 040, 136	1, 533, 054	1, 776, 170	2, 249, 655	2, 547, 596	3, 077, 445. 81	7, 507, 202. 08	7, 719, 127. 47	7, 923, 388. 06	8, 827, 062. 99
Kansas	186, 066	268, 471	387, 588	585, 762	830, 878	978, 837	1, 150, 000. 00	1, 419, 345. 50	1, 400, 000. 00	[1] 3, 100, 000. 00	3, 435, 606. 00
Kentucky	52, 000	85, 883	117, 117	184, 741	287, 314	402, 250	565, 520. 21	815, 549. 31	1, 771, 887. 02	2, 140, 444. 31	2, 678, 732. 89
Louisiana	[3] 10, 000	[3] 12, 000	75, 600	112, 000	166, 835	240, 000	306, 000. 00	390, 000. 00	453, 276. 00	1, 756, 226. 42	2, 191, 240. 81
Maine	138, 509	192, 542	268, 412	363, 562	491, 696	570, 171	685, 570. 25	818, 755. 50	1, 004, 750. 25	1, 417, 507. 57	1, 660, 268. 17
Maryland	150, 000	268, 231	386, 565	565, 302	807, 395	1, 189, 984	1, 776, 410. 22	2, 124, 924. 84	2, 460, 162. 04	2, 824, 843. 91	3, 536, 955. 20
Massachusetts	764, 154	923, 961	1, 235, 724	1, 602, 958	1, 969, 994	2, 184, 821	2, 667, 853. 85	3, 860, 231. 70	4, 717, 389. 30	5, 685, 527. 05	6, 989, 633. 25
Michigan	190, 329	([4])	373, 833	1, 739, 344	2, 471, 271	2, 875, 266	3, 719, 433. 39	5, 754, 900. 96	6, 751, 924. 51	8, 385, 022. 17	10, 500, 786. 05
Minnesota	40, 000	132, 398	[3] 160, 540	82, 469	100, 000	1, 076, 811	218, 469. 50	143, 794. 50	5, 672, 424. 61	6, 543, 685. 77	7, 316, 772. 03
Mississippi	24, 735	51, 146	76, 700	175, 000	250, 000	335, 000	400, 000. 00	800, 000. 00	751, 946. 63	1, 179, 803. 00	1, 077, 616. 22
Missouri	173, 510	235, 873	323, 289	439, 315	617, 942	1, 394, 762	1, 725, 076. 70	2, 111, 696. 85	2, 505, 353. 90	3, 512, 182. 97	4, 016, 383. 60
Montana	12, 000	27, 000	33, 120	52, 768	290, 936	350, 914	407, 848. 00	416, 245. 00	594, 520. 50	619, 899. 50	729, 621. 50
Nebraska	26, 000	34, 325	[3] 183, 000	311, 334	451, 303	536, 897	304, 450. 55	2, 800, 000. 00	2, 824, 811. 25	3, 031, 699. 93	3, 353, 175. 32
Nevada	3, 323	4, 331	7, 875	20, 116	31, 166	31, 083	37, 550. 75	103, 318. 33	102, 800. 00	120, 937. 73	153, 888. 10
New Hampshire	152, 834	185, 288	257, 776	344, 434	425, 305	509, 335	599, 621. 25	654, 702. 04	876, 322. 14	1, 246, 098. 46	1, 571, 326. 96
New Jersey	661, 446	814, 536	1, 062, 923	1, 406, 806	1, 923, 164	2, 431, 757	2, 931, 902. 15	3, 503, 936. 76	3, 974, 063. 75	6, 251, 418. 50	7, 653, 780. 37
New Mexico	15, 084	19, 663	29, 625	47, 865	80, 843	105, 631	111, 150. 00	200, 000. 00	198, 632. 77	243, 813. 61	295, 000. 00
New York	1, 275, 727	1, 529, 852	1, 991, 181	2, 658, 042	4, 284, 144	4, 945, 298	5, 984, 659. 50	8, 863, 250. 59	10, 288, 858. 25	12, 736, 364. 37	19, 862, 441. 52
North Carolina	60, 000	89, 580	123, 000	206, 101	321, 923	394, 739	1, 313, 950. 73	1, 785, 000. 00	2, 259, 240. 43	2, 715, 331. 58	3, 728, 044. 72
North Dakota	41, 961	55, 964	79, 245	125, 283	211, 536	471, 429	636, 842. 40	691, 500. 00	683, 052. 45	698, 931. 70	760, 852. 45
Ohio	457, 538	685, 457	984, 622	1, 286, 405	1, 766, 427	2, 125, 426	2, 593, 000. 00	6, 400, 000. 00	6, 894, 159. 73	7, 888, 992. 38	9, 662, 370. 29
Oklahoma	3, 000	13, 500	154, 892	555, 011	853, 659	1, 102, 380	1, 178, 130. 27	2, 500, 000. 00	2, 619, 713. 49	2, 729, 169. 15	3, 217, 770. 84
Oregon	56, 873	77, 592	108, 881	146, 232	196, 787	461, 422	602, 239. 00	2, 085, 168. 50	2, 334, 931. 25	3, 340, 519. 58	4, 069, 609. 40
Pennsylvania	841, 062	1, 185, 039	1, 665, 276	2, 325, 057	3, 268, 025	4, 048, 186	5, 090, 921. 00	8, 090, 873. 04	9, 470, 174. 31	12, 575, 380. 56	15, 844, 303. 80
Rhode Island	129, 851	157, 020	206, 440	264, 737	346, 117	385, 608	477, 223. 25	531, 462. 75	848, 723. 59	1, 139, 742. 77	1, 286, 659. 47
South Carolina	10, 000	14, 000	15, 000	10, 000	113, 557	300, 217	389, 034. 68	527, 868. 13	741, 114. 79	734, 856. 18	902, 608. 69
South Dakota	89, 170	125, 000	[3] 180, 000	140, 746	210, 592	282, 742	322, 340. 50	784, 000. 00	720, 587. 00	743, 232. 00	1, 130, 959. 27
Tennessee	[3] 9, 000	39, 538	[3] 34, 000	186, 953	322, 200	390, 000	585, 181. 95	1, 215, 776. 04	1, 387, 870. 10	1, 592, 230. 14	2, 049, 653. 27
Texas	16, 000	20, 000	20, 000	20, 000	858, 978	2, 039, 589	2, 624, 334. 29	3, 510, 355. 97	3, 806, 395. 25	4, 261, 488. 67	5, 441, 508. 59
Utah	3, 000	4, 852	[3] 60, 000	93, 494	170, 707	229, 203	291, 325. 96	350, 933. 29	441, 359. 88	729, 455. 00	430, 104. 72
Vermont	111, 460	154, 267	218, 480	297, 992	363, 541	398, 856	460, 190. 87	555, 422. 38	668, 288. 50	781, 982. 35	938, 860. 30
Virginia	83, 611	120, 814	176, 875	271, 266	518, 566	684, 636	900, 000. 00	1, 822, 736. 16	2, 021, 146. 09	2, 467, 346. 93	3, 200, 161. 66
Washington	48, 356	60, 506	238, 717	350, 052	519, 526	875, 391	2, 325, 323. 53	2, 828, 896. 10	3, 140, 730. 74	3, 291, 671. 70	3, 898, 597. 77
West Virginia	40, 000	60, 648	128, 952	198, 436	359, 339	447, 705	1, 008, 083. 31	1, 280, 193. 28	1, 250, 525. 82	1, 936, 079. 29	2, 608, 508. 37
Wisconsin	190, 770	293, 580	431, 977	615, 721	861, 278	2, 076, 701	2, 502, 852. 00	3, 127, 073. 00	3, 671, 645. 50	4, 088, 570. 00	4, 958, 933. 55
Wyoming	7, 920	12, 140	19, 880	35, 625	57, 421	80, 000	102, 114. 50	267, 179. 35	288, 121. 88	316, 849. 50	414, 096. 89
Total	8, 192, 253	12, 382, 031	18, 245, 711	25, 865, 369	37, 501, 233	51, 477, 419	64, 697, 255. 48	102, 546, 212. 25	122, 478, 654. 33	152, 047, 823. 74	188, 970, 992. 24

[1] Approximate. [2] State registrations only. [3] Estimated. [4] Registration law held unconstitutional.

TABLE IV.—*Gasoline taxes, 1923.*

State.	Total gross receipts.	Amount applicable to highway work by or under supervision of State highway department.	Tax in cents per gallon on Jan. 1, 1923.	Tax in cents per gallon on Jan. 1, 1924.	Date on which change in rate of tax became effective.
Alabama	$1, 133, 085. 49			2	Mar. 1.
Arizona	474, 123. 04	$118, 530. 76	1	3	June 9.
Arkansas [1]	1, 219, 198. 75	301, 094. 76	1	4	Jan. 1, 1924.
California	2, 518, 893. 00	1, 259, 446. 00		2	Sept. 30.
Colorado	846, 353. 12	402, 017. 73	1	2	Aug. 1.
Connecticut	880, 222. 70	880, 222. 70	1	1	
Delaware [2]	88, 579. 28	88, 579. 28		2	Jan. 1, 1924.
District of Columbia					
Florida	1, 641, 042. 25	1, 150, 355. 99	1	3	July 1.
Georgia	1, 502, 503. 49	247, 666. 55	1	3	Oct. 1.
Idaho	396, 487. 18	396, 487. 19		2	Apr. 1.
Illinois					
Indiana	2, 906, 428. 25	2, 514, 755. 83		2	June 1.
Iowa					
Kansas					
Kentucky	680, 435. 30	680, 435. 30	1	1	
Louisiana	754, 437. 85	754, 437. 85	1	1	
Maine	286, 076. 97	285, 839. 84		1	July 7.
Maryland	688, 304. 02	688, 304. 02	1	2	Jan. 1, 1924.
Massachusetts [3]					
Michigan					
Minnesota [4]					
Mississippi	467, 855. 53	187, 142. 21	1	1	
Missouri					
Montana	441, 249. 10	75, 877. 10	1	2	July 1.
Nebraska					
Nevada	115, 843. 24	60, 000. 00		2	Mar. 20.
New Hampshire [6]	[5] 163, 064. 64	161, 823. 10		2	Jan. 1, 1924.
New Jersey					
New Mexico	165, 000. 00	156, 750. 00	1	1	
New York					
North Carolina	2, 909, 904. 74	[7] 2, 900, 000. 00	1	3	Apr. 1.
North Dakota	461, 081. 71		1	1	
Ohio					
Oklahoma	599, 000. 00	599, 000. 00		1	July 1.
Oregon	1, 958, 141. 37	1, 885, 421. 15	2	3	May 24.
Pennsylvania	5, 491, 522. 66		1	2	July 1.
Rhode Island					
South Carolina	1, 511, 452. 56	411, 327. 78	2	3	Mar. 23.
South Dakota	624, 692. 44	[7] 565, 000. 00	1	2	
Tennessee	812, 356. 68	801, 502. 36		2	Apr. 1.
Texas	1, 215, 623. 36	911, 717. 52		1	June 15'
Utah	404, 085. 81	106, 902. 75		2½	Mar. 8.
Vermont	168, 172. 81	168, 172. 81		1	Apr. 1.
Virginia	1, 556, 920. 99	[8] 1, 037, 947. 32		3	June 27.
Washington	1, 225, 149. 66	1, 225, 149. 66	1	2	Jan. 1, 1924.
West Virginia	[9] 366, 490. 00	366, 490. 00		2	July 27.
Wisconsin					
Wyoming	140, 161. 62	140, 161. 62		1	Mar. 1.
Total	36, 813, 939. 61	21, 528, 559. 18			

[1] One cent from Jan. 1 to Apr. 1; 3 cents Apr. 1 to Dec. 31, inclusive.
[2] One cent from Apr. 22 to Dec. 31, inclusive.
[3] Act passed by legislature, but referendum invoked. Election November, 1924.
[4] Constitutional amendment permitting a tax on gasoline to be voted on November, 1924.
[5] To Dec. 1, 1923.
[6] Tax of 1 cent per gallon effective July 1 to Dec. 31, inclusive.
[7] Approximate.
[8] One-third of total receipts returned to counties for county highway work.
[9] Collections from July 27, when tax became effective, to Nov. 1.

THE BRICK ROADS OF FLORIDA.

OBSERVATIONS OF THE BEHAVIOR OF BRICK SURFACES LAID ON CONFINED SAND SUBGRADES.

By C. A. HOGENTOGLER, Highway Engineer, U. S. Bureau of Public Roads.

Brick roads in Florida are generally laid directly upon the sand subgrade. The brick are filled with sand, cement grout, or a bituminous filler, and are retained at the sides of the road by cypress, vitrified brick, or concrete curbs. The shoulders are sand, shell, clay, or limerock.

Brick pavements of this type have practically no "beam strength." Traffic loads are supported by the confined sand of the subgrade, the brick surface serving chiefly as a wearing course.

The cement-grout filled pavements offer less tractive resistance and more resistance to deterioration than the sand-filled roads. They distribute the wheel loads over a wider area of subgrade, but when they do break up, as they do when laid directly on the sand subgrade, the relaying value of the brick is much less than those of sand-filled pavements. If in the future this type of surface is laid with adequate base and shoulders and provision for expansion, it should make a very satisfactory pavement.

Sand-filled pavements in service from 8 to 14 years, receiving little or no intelligent maintenance, have 70 per cent of their surface functioning as fair and good road. The remaining 30 per cent, while in need of reconstruction, has a reconstruction value of 80 per cent of the new construction cost. Pavements of this type are believed to have been economical and well adapted to a State in which uncertain development precluded a forecast of future traffic conditions.

Sand is ineffective as a filler. It is not waterproof; it offers but little frictional resistance to the movement of the brick; and it can not be retained in place.

Bituminous fillers have desirable waterproofing and plastic properties. They do not reduce the salvage value of the pavement.

Indications are that limerock dust, sand mixed with limerock dust or clay, or sand treated with a light oil, would make satisfactory fillers.

Indications are that the brick roads can be strengthened to accommodate heavy traffic or to hold up in locations where good drainage is impracticable by laying a base course of compacted limerock which will provide additional confinement of the sand subgrade. Such bases are not like rigid slabs which have "beam strength"; their strength does not lie in the bond between the individual stones as in the macadams; their chief value lies in their ability to remain at all times in contact with the sand subgrade. They have little supporting power in themselves, but they do make available the maximum support of the subgrade. They also prevent loss of sand through the crevices between the brick.

Shoulders of limerock or other material capable of providing side support for the pavement are more necessary than thick bases.

Florida State Highway Commission reports indicate a maximum daily traffic over such roads amounting to 200 motor trucks on the two-way road between Lakeland and Tampa and 157 on the narrow one-way road between Sanford and Kissimmee. The number of trucks averaged from 10 to 30 per cent of the total number of vehicles.

It is important to note that practically all of the Florida road traffic is carried on pneumatic tires, for it is quite probable that equally good results as herein reported would not have been secured had the heaviest trucks operated on solid tires. It should also be noted that Florida traffic is comparatively light. The gross load limitation is 16,000 pounds on pneumatic tired vehicles and 8,000 pounds on vehicles having solid tires

RECENT highway research has developed considerable information concerning the strength and wearing properties of rigid surfaces possessing what is called beam strength when such surfaces are laid on subgrades of questionable bearing value.

This article presents the results of a number of observations of a kind of road which is the exact antithesis of such construction. The brick roads of Florida have little or no beam strength, but they are laid on a subgrade which, when properly confined, has high supporting value.

The unpaved sand roads are exceedingly unstable. Their tractive resistance is high. Yet the surfacing of such roads with a pavement of brick, in many instances without other filler than the sand itself, and the installation of a curb along the edges of the brick surface converts them into excellent thoroughfares which have been a source of great satisfaction to thousands of winter visitors to the "Land of Easter."

The Florida sand soils lack stability because of the poor gradation of the sand particles and their low clay content. When properly compacted and confined, however, they offer high resistance to volume change, a fact which, with the absence of frost, accounts for their extensive use as bases for brick pavements. The characteristic instability of the soil is indicated by Figure 1, which shows the result of the passage of a few vehicles. That sand-filled brick surfaces have little or no beam strength is apparent in Figure 2, which shows the separation of brick and loss of filler on State route No. 1 between Jacksonville and Lake City. This surface, which is representative of the Florida construction, has withstood traffic for 14 years, including the war traffic of truck trains, gun mounts, and carriages. While this surface is not in perfect condition, its principal defects are directly traceable to lack of stability, the one undesirable characteristic of the sand subgrade. It is clear from a study of these roads that when subgrades have stability and high supporting power and are subject to little volume change the chief function of the surface is that of a wearing course, capable of utilizing the maximum support offered by the subgrade.

STAGES OF DETERIORATION NOTED.

The rural brick surfaces of Florida are usually 9 or 15 feet wide and are supported by cypress, vitrified brick, or concrete curbs. Sand, cement-grout, and bituminous fillers are used, and the shoulders consist of sand, shell, clay, or limerock.

The deterioration of sand-filled surfaces is first indicated by a more or less uniform settlement along the curbs, accompanied in some instances by transverse separation of the brick.

The second stage of deterioration is indicated by well-defined grooves or edge depressions, loss of filler, transverse and longitudinal movement of the brick, and, in some cases, slight unevenness of surface. Looseness causes the bricks to rattle during the passage of vehicles, and broken bricks are often displaced.

The third stage of deterioration or failure of sand-filled pavements is indicated by excessive rutting, separation and displacement of bricks, and unevenness of surface.

The progress of deterioration in bituminous-filled surfaces could not be determined because of the newness of this type of construction in Florida. All the observed surfaces of this type, however, showed separation of brick, accompanied in some instances by slight grooving. The latter was found principally on curves.

FIG. 1.—Graded natural Florida soil road. State Route No. 2, south of Crescent City.

In cement-grout-filled surfaces the first signs of deterioration noted were cracks, which in some cases, were so frequent as to divide the pavements into small blocks. These cracks, which generally were found only on close inspection, while they did not change perceptibly the contour of the surface, did change the pavement from a rigid to a more or less flexible top.

When the cracks became noticeable due to slight feathering of the edges or separation of the pavement blocks, and when these blocks were not displaced vertically, a second stage of deterioration was indicated.

When excessive cracking separated practically every brick, or when individual areas became so displaced that traffic was seriously hindered, the third stage of deterioration or failure was indicated.

Surfaces showing only the first indications of deterioration offered all of the advantages that could be expected from the best paved roads.

In the second stage of deterioration, though the pavements showed plainly the effects of climate and traffic, and in many cases indications of gross neglect, they offered but little inconvenience to traffic and in general functioned as first-class roads. One of the interesting features of the narrow, sand-filled surfaces was that even deep grooves did not as a rule impair the smooth riding qualities of the pavement. They inconvenienced traffic to some extent, however, when vehicles passed each other.

FIG. 2.—State Route No. 1 between Jacksonville and Lake City, showing lack of "beam strength."

The roughness of surfaces in the third stage of deterioration seriously inconvenienced traffic which, to prevent accident, was forced to move at considerably reduced speed.

EXAMPLES OF PAVEMENTS IN FIRST STAGE OF DETERIORATION.

The following pavements were representative of those which showed no greater deterioration than that described as the first stage:

Park Avenue, Sanford, a view of which is shown in Figure 3, is a residential street constructed in 1906, with sand-filled, repressed brick, laid on edge. The pavement was still giving excellent traffic service.

The Boulevard, DeLand, is representative of 4 miles of cement-grout-filled, wire-cut-lug pavement constructed in 1916–17, at a cost of $1.65 per square yard. Ranging from 24 to 44 feet in width, these pavements were laid in business as well as residential streets. The main business street carried also the traffic of State route No. 2, Orlando to DeLand. The principal defects noted were one blow-up at a street and grade intersection, one longitudinal crack caused by the fail-

FIG. 3.—Park Avenue, Sanford—A sand-filled pavement in the first stage of deterioration, still giving excellent traffic service.

FIG. 4.—Bituminous-filled relaid brick surface between Jacksonville and Atlantic Beach, giving good service though in the first stage of deterioration.

ure of a fill, and several cracks adjacent to a railroad crossing.

The bituminous-filled pavement between Jacksonville and Atlantic Beach, a view of which is shown in Figure 4, is 18 feet wide. It was relaid in 1919 with repressed bricks from the sand-filled pavement constructed in 1909. When observed it showed slight transverse separation of the brick and indications of grooving, especially on curves.

A section of State route No. 1, in Jacksonville, a cement-grout-filled, wire-cut-lug surface, shown in Figure 5, was in excellent condition after four years of service.

A section of State route No. 2, between Orlando and Sanford, was another cement-grout-filled pavement of 3½-inch wire-cut-lug brick, the surface being 8 feet wide. It was laid in 1917 with concrete curbs and showed behavior typical of narrow pavements of this type. In a length of 7.6 miles 16 breaks were noted. Five of these were blow-ups which occurred at grade apexes. Two breaks were adjacent to railroad crossings and five occurred at curves. Figure 6 shows a break near a curve in this pavement. Water can be seen in the crack between the curb and the shoulder. The surface had been pushed outward 5 inches from the inside curb on a 90° turn, and about 2½ inches on a 30° turn. The outside curb had been broken off in the latter case.

FIG. 5.—Cement-grout-filled brick surface, State Route No. 1, near Jacksonville, giving excellent service after four years, though in the first stage of deterioration.

THE SECOND STAGE OF DETERIORATION ILLUSTRATED.

Pavements in the second stage of deterioration were represented by the following:

The section of State route No. 4, Jacksonville to Waycross, 15 feet wide, consisting of sand-filled, repressed brick, laid on the side, with 4 by 10 inch concrete and brick curbs, was constructed in May, 1910, at a cost of $1.48 per square yard. It is about 5 miles long, beginning 3½ miles from the city limits of Jacksonville. As shown in Figure 7, a good, even riding surface was presented in spite of the fact that the curbs were pushed out of line, that a considerable transverse separation of the brick existed, and that along the side edge there were depressed areas which held water after rains. Increased settlement was noted on fills through cypress swamps. Relaying of

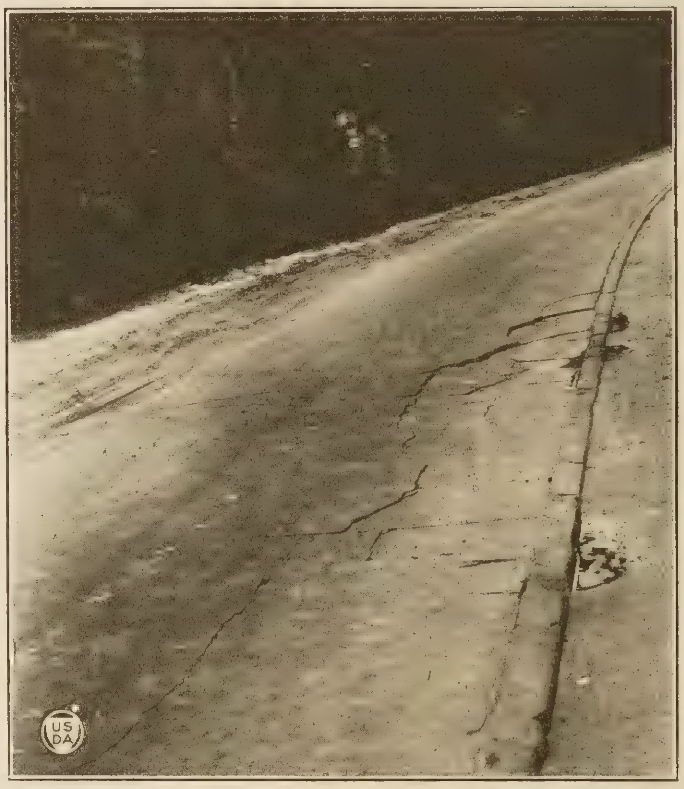


FIG. 6.—Break on curve of cement-grout-filled surface—State Route No. 2, between Orlando and Sanford.

uneven areas over culverts and salamander holes and mounds, caused probably by stumps in the subgrade, and application of additional filler would make this a first-class road.

Two sections of the above road each one-half mile in length were constructed with depressed centers, as shown in Figure 8. More or less uniform depression of brick along the edges was noted, as well as a slight depression several feet from the left-hand edge. The curbs were pushed out of line, but the sand filler seemed to be intact. These depressed-center sections were constructed in 1909, after serious washing of the shoulder of the previous pavement. Although water had been flowing down the middle of the road for something like 14 years, these sections presented very good riding surfaces. They also eliminated the trouble found on the majority of Florida roads—that of water standing in depressions along the curb.

Fig. 7.—Sand-filled brick surface, north of Jacksonville. In the second stage of deterioration but still giving good service.

Figure 9 illustrates the loss of filler and the brick movement characteristic of the second stage of deterioration in a sand-filled pavement.

The section of State route No. 4, south of St. Augustine, is 16 feet wide. It was graded in 1908, paved in 1909–10 with sand-filled, repressed brick laid on the side, and retained by brick curbs. This road carries practically all of the tourist traffic between north and south Florida, including busses which have a capacity of 35 passengers and run at a speed of about 35 miles an hour. In some places this road has grass shoulders (fig. 10), and considerable grass grows in the filler between the brick. There is more or less depression of the sides in all sections, which is particularly noticeable in the lower view, Figure 10. In addition to the depression of the sides a longitudinal movement of the brick amounting to about three-fourths of an inch was observed.

Representative also of the second stage of deterioration were the sections of sand-filled brick surfaces 9 feet wide between St. Augustine and Hastings. The typical condition of these pavements is shown by Figure 11.

Fig. 8.—Section of sand-filled brick pavement with depressed center—State Route No. 4—north of Jacksonville. Although water has flowed down the middle of this road for 14 years it still presents a good riding surface.

THE THIRD STAGE OF DETERIORATION.

The following surfaces were representative of those in the third stage of deterioration:

A section of sand-filled brick surface with wooden curbs between Orlando and Sanford, a view of which is shown in Figure 12. In this pavement, which was laid in 1916, a very uneven surface was caused by excessive brick movement.

Orange Park Road, passing the United States Government reservation, south of Jacksonville. The unevenness and brick separation in this sand-filled surface, which was constructed in 1910-11, 15 feet wide with brick curbs, are shown in Figure 13.

Sections of narrow, sand-filled brick surface between Hastings and Ormond Beach, a typical view of which is shown in Figure 14. This road was in worse condition than any other seen in Florida. In some places the concrete curbs were 1 foot out of line. The base and shoulders consisted of typical "ball-bearing" sand, and water stood along the sides 6 to 18 inches from the surface.

Fig. 9.—Section of sand-filled surface between Jacksonville and Atlantic Beach, showing movement of brick and loss of filler.

TRAFFIC SERIOUSLY INCONVENIENCED ON ONLY 25 PER CENT OF PAVEMENTS INSPECTED.

Exclusive of city streets, about 300 miles of brick pavement were inspected. About 35 per cent of this length consisted of excellent surfaces, which either showed no signs of deterioration or in which brick movement, settlement, or cracking had not developed to an extent requiring immediate repair except in small, isolated areas. About 40 per cent consisted of roads which showed marked loss of filler, appreciable cracking, brick movement, grooving, and spread of curbs. Some of these pavements retained remarkably smooth riding qualities, while in others, such unevenness as existed, inconvenienced traffic but little. The remaining 25 per cent consisted of surfaces on which traffic was seriously inconvenienced or hindered by marked brick movement, loose bricks, peaked centers, nonuniform grooving or displacement of individual parts.

The above percentages are based on a classification of whole sections. If the general characteristics of a section were such as to place it within the third class the length of the whole section was used in determining the percentage. If considered foot by foot, the first-class percentage would be increased, since there were short lengths of excellent surface in many sections whose general condition indicated second and third stages of deterioration.

INADEQUATE SIDE SUPPORT THE CAUSE OF MAJOR DEFECTS.

It is apparent that inadequate confinement of the sand subgrade was responsible for the major defects

Fig. 10.—(UPPER) SAND-FILLED SURFACE ON STATE ROUTE NO. 4, JACKSONVILLE TO ST. AUGUSTINE, SHOWING DEPRESSION OF THE EDGES OF THE PAVEMENT. (LOWER) ANOTHER VIEW OF THE SAME ROAD SHOWING MARKED UNEVENNESS.

in the Florida pavements, and also that, in the main, this inadequate confinement was due to insufficient side support. Defects not attributable to the above cause were initial settlement, cracking and breakage, and unevenness found in lowland and swamp locations.

Initial settlement in both sand and bituminous-filled surfaces was probably due to settlement of the sand subgrade and can not be eliminated in this type of construction. That even a nonrigid base course will not entirely eliminate this defect is indicated by Figure 15, a view of a sand-filled, repressed brick surface, with concrete curbs, shell base and shoulders, laid between Jacksonville and St. Augustine in 1916. This minor defect can be reduced to a minimum by adequately compacting the subgrade prior to laying the base and by sufficiently rolling the bricks before applying the filler. Retention of rain water on the surface, the chief inconvenience caused by slight settlement will be avoided by laying the bricks so that their tops are slightly above the top of the curb.

Cracking and breakage in cement-grout-filled pavements were due to surface movement caused by expansion and the adjustment of the rigid slabs to their new positions. These defects can not be eliminated in this type of pavement.

Unevenness of surfaces in lowland and swamp locations was attributed both to the character of the sand and the presence of water. The sand in these locations is excessively fine and especially when wet has considerably less stability than normal soil. There was some indication also that this type of sand works up through the crevices between the brick and is either washed or blown away. The injurious effect of water in all types of sand was plainly evident, although in some cases, very good road surfaces were found in locations where elimination of water was impracticable.

Where good drainage existed, the effect of curbs and shoulders on the behavior of the pavements was very apparent. In some cases, total absence of shoulders allowed the subgrade to be washed away. Neglect of this kind was undoubtedly responsible for nonuniform settlement in sand-filled, and displacement of blocks in cement-grout-filled surfaces. In other cases, insufficient side resistance allowed the curb movement which was primarily responsible for grooves and excessive separation movement and unevenness of the brick.

Figure 16, a view of the Tildenville Road, relaid April, 1923, shows the absence of shoulders and a space one-half inch wide between sections of relaid curbing. Within a radius of 18 inches around the joint the sand filler as well as about one inch of the subgrade had been washed away. When this amount of displacement occurs in several months, one can easily conjecture what would happen in a period of years.

TYPICAL DEFECTS OF A CEMENT-GROUT-FILLED SECTION.

A cement-grout-filled, wire-cut-lug surface between Orlando and Bithlo showed very clearly the influence of shoulders on the behavior of pavements. The first 100 feet, beginning at the end of East Colonial Street, Orlando, had good sand shoulders flush with the pavement and was practically free from cracks. Slightly beyond this, there were indications that water flowed along the north side, and coincident with this condition a longitudinal crack 18 inches from the north edge of the pavement was noted. Some distance farther along the route poor drainage, mucky sand soil, inefficient shoulders, and practically no curbs were encountered, and, as would be expected, considerable breakage of surface. Figure 17 shows the absence of shoulders and the remains of the old cypress curb. Although the pavement had little support this section was in very good condition. Figure 18 shows the breakage which occurred where shoulders were absent and water stood within 6 inches of the top of the surface. The displacement of surface shown in Figure 19 could not have occurred had the sand subgrade not been removed, and since the shoulders adjacent to this and to several other similar breaks were from 6 to 8 inches below the surface, water probably was the cause of the settlement.

In 2.2 miles there existed several depressed areas such as the one shown in Figure 19, several locations where edge breaks occurred, such as the one shown in Figure 18, and four blow-ups extending from 50 to 150 feet each. The combined length of all breaks was somewhat less than 10 per cent of the length of the surface. The remainder of the road, although considerably cracked, was in the good riding condition shown in Figure 17. Traffic failures were noted only where no shoulders existed. The breakage in this road occurred between April and July, 1923, during which time about 5,000 loads of limerock were hauled over it. Figure 20 shows one of these loads consisting of three cubic yards of rock on the truck and two on the trailer.

In passing from the cars to the road these trucks passed over Mills and East Colonial Streets in Orlando, and the indications were that they traveled in the same path on each trip. Both street surfaces were sand-filled, repressed brick, laid flat. In some places on the former, which had been in service for about one year, slight indications of settlement in the wheel tracks were found on close examination. In the latter, which had been in service about two years, the inside

Fig. 11.—Grooves in a narrow sand-filled brick surface between St. Augustine and Hastings.

path was over a gas or water main trench and there was settlement ranging in depth from one to two inches. Rigid examination, however, failed to disclose any indication of settlement in the outer wheel path. At the intersection of the two streets, appreciable settlement was noted where the wheel paths crossed a gutter which carried surface water during rains.

Fig. 12.—Sand-filled brick surface with wood curbs, between Orlando and Sanford. This surface is in the third stage of deterioration. Note the settlement and separation of the brick.

VALUE OF SIDE SUPPORT ILLUSTRATED.

The effect of side support in sand-filled pavements was illustrated by the road between Orlando and Kissimmee, which was constructed 9 feet wide, with 4 by 10 inch curbs in 1916. On the first section, between Orlando and Pine Castle, a distance of 3 miles, clay shoulders were laid immediately after construction; on the second section 2 miles south from Pine Castle the shoulders were laid with rock between 18 months and 2 years later; and along the third section, rock shoulders were laid partly last year and partly this year. That portion where shoulders were not laid until this year was more rutted than any other part of the Orlando-Kissimmee Road. While rutting and separation seemed more pronounced in the second than in the first section, it was only in the third section that many areas were relaid, these areas being principally where the road was subjected to action of surface water.

Displacement of the sand subgrade due to vertical movement of curbs was noted on the Orlando-Winter Garden Road and was probably responsible for the failure shown in Figure 21. Only two conditions of this kind were found in a length of 3.2 miles of this sand-filled, repressed-brick surface with concrete curbs, which was laid in 1916. Bulging of the curbs began soon after construction and was caused by expansion. Until spaces were found under the curb, the pavement was thought to have settled. This upward movement of the curbs was increased by pressure of the subgrade sand, which was forced into the spaces beneath them, causing variation in the curb line and settlement of adjacent bricks. Although deeply grooved as shown in Figure 22, a smooth-riding surface existed. This surface is now being relaid, 15 feet wide.

The Orlando-Kissimmee Road referred to above is part of the Sandford-Plant City Road, which, according to a traffic census taken by the Florida State highway commission, January to June, 1923, carried heavier truck traffic than any of the other roads observed. Because all parts of this road received the same intelligent maintenance, the behavior of its various surfaces was considered indicative of their adequacy for Florida conditions. Considering only those surfaces 9 feet wide which had been in service about eight years, it was noted that of the cement-grout-filled surfaces, all of which had 4 by 10 inch concrete curbs, 95 per cent were in class 1, 2½ per cent in class 2, and 2½ per cent, due to failure of the sand fill, were in class 3. Of the sand-filled surfaces, those which had 4 by 10 inch concrete curbs and limerock shoulders laid at the time of construction were in class 1, those which had 4 by 10 inch concrete curbs and sand shoulders were in class 2, and those with wood curbs as well as a short section through a swamp with concrete curbs were in class 3. Short sections of the sand-filled surfaces with concrete curbs and sand shoulders, especially at locations subjected to water action, had been relaid.

RELAYING VALUE OF SAND-FILLED SECTIONS HIGH.

Apparently the cement-grout-filled offered great resistance to deterioration than the sand-filled surfaces. The present value of the surfaces, however, depends not alone on their condition, but also upon the relaying value of the brick. This relaying value is of special importance in Florida since, at 1923 prices, the cost of brick was about 73 per cent of the total cost of the surface. There was but little salvage value in cement-grout-filled pavements, while in sand-filled pavements there was considerable.

On a sand-filled section of the Jacksonville-Atlantic Beach Road, laid in 1909 and relaid in 1919, the breakage of brick was less than 1 per cent. On one contract in Orange County 650 square yards of new brick were required in relaying 90,000 square yards of surface originally constructed in 1916. When relaid without disturbing the curbs, a greater percentage of new brick was required because of increased pavement width. Owing to the very small breakage, however, practically the entire cost of the brick can be considered as a permanent investment. The conclusion drawn from the observations was that even when a sand-filled pavement had deteriorated to a condition characteristic of the third stage, at present rates about 70 per cent of the initial investment still remained, the remaining 30 per cent representing the price of the service afforded by the road. When, however, failure occurs in a pavement of low salvage value, such as a cement-grout-filled brick, almost the entire first cost is lost. This pertinent fact must be given proper consideration in the selection of a pavement.

The high salvage value of sand-filled brick was indicated also by the difference between bids for new and relaid pavements. This difference indicated a relaying value of about $1.95 per square yard, or about 80 per cent of the total cost of new construction. It is interesting to note that because of present high prices, the indicated relaying value ($1.95) of bricks in the Orlando-Winter Garden Road was 40 cents greater than the cost ($1.55) per square yard of laying the surface seven years ago.

CONCLUSIONS AND RECOMMENDATIONS.

It is believed that the foregoing descriptions and discussion of the behavior of Florida brick pavements warrant the following conclusions and recommendations:

In general, cement-grout-filled surfaces offered less tractive resistance and more resistance to deterioration than those in which sand filler was used. The bond between bricks minimized the danger of separation and, when adequate shoulders existed, required only wooden side forms. Figure 23 shows that cement-grout-filled surfaces conformed to changing subgrade profiles without becoming rough. This type of surface, because of its rigidity, distributed wheel loads over larger areas of subgrade and consequently subjected the soil to vertical pressure of less intensity than other types. It is not believed, however, that this advantage was of sufficient importance to compensate for the breakage caused by blow-ups and the loss of relaying value of the brick which cement-grout filler causes. If in the future this type of surface is laid with adequate base and shoulders and provision for expansion, it should make a very satisfactory pavement.

Because of the high salvage value of the brick and the small cost of relaying, the sand-filled pavements were economical and especially well adapted to a State in which uncertain development precluded a forecast of future traffic conditions. When pavements which have been in service from 8 to 14 years, and which in

FIG. 13.—(UPPER) LONGITUDINAL MOVEMENT OF BRICK IN THE ORANGE PARK ROAD. NOTE GRASS GROWING IN THE SAND FILLER. (LOWER) TRANSVERSE SEPARATION OF BRICK PERMITTED BY SPREADING OF CURBS.

that time in many cases have received little or no intelligent maintenance, have 70 per cent functioning as fair and good roads and the remaining 30 per cent, though in need of reconstruction, has a relaying value equivalent to 80 per cent of the new construction cost, such pavements can not be considered as other than satisfactory.

By making a few changes in future construction, however, it is believed that many of the defects at present existing in the flexible brick tops can be considerably reduced or entirely eliminated.

Sand as filler is very ineffective. It is not waterproof; it affords but little frictional resistance to the movement of the brick, and it can not be retained in place. As a rule, the sand-filled pavements observed were but half filled. Indications were that limerock dust, sand mixed with limerock dust or clay, or sand treated with a light oil, would make satisfactory fillers.

Bituminous fillers seem desirable because of their waterproofing and plastic properties, and also since they do not reduce the salvage value of the pavements.

FIG. 14.—Failure of narrow, sand-filled surface between Hastings and Ormond Beach. This is a third-stage pavement.

While it was evident that 4 by 10 inch curbs (concrete or vitrified brick) were incapable of resisting without movement the pressure to which they were subjected, it is believed that, rather than increase the curb size, special shoulders should be laid to furnish the required additional side support.

Sand shoulders, like sand filler, many times meant no shoulders at all. Especially along the narrow roads which carried considerable traffic, sand shoulders could not be retained in place. When covered with grass, they could be retained along the wide roads, but even so, their resistance was insufficient to prevent curb spreading and the accompanying defects.

LIMEROCK A USEFUL MATERIAL FOR SHOULDERS AND BASE.

Indications were that limerock shoulders were very effective and desirable not only on account of their additional resistance but also for the additional effective road width which they furnish.

Where heavy traffic is to be accommodated, and also in all locations where good drainage is impracticable, additional confinement of the soil foundation by means of a base course is believed desirable. For these base courses also the Florida soft limerocks are the most

FIG. 15.—Showing settlement in a narrow, sand-filled surface laid on a shell base This is a section of the Jacksonville-St. Augustine road.

accessible materials. A piece of limerock placed in water will disintegrate, but when thoroughly puddled and rolled, it forms a smooth surface which apparently is little affected by moisture. These surfaces are not hard enough to resist surface wear but seem to have considerable resistance to internal disintegration.

Figure 24 shows a limerock base before rolling. Figure 25 shows the smooth surface obtained by rolling and also its lack of beam resistance. This case on the Tildenville-Black Lake Road was down two weeks when the sand subgrade was washed out, allowing the limerock base to fall. Figure 26 shows a limerock surface which was laid in 1914 by placing the material on the road and allowing traffic to compact it. Figure 27 is a view of the first limerock road constructed in Florida. This section of State-aid Route No. 5 between Ocala and Tampa was properly compacted by a power roller in 1913 and has been maintained with sand. It has resisted both traffic and climate remarkably well and at present is hard and compact and undoubtedly has considerably more slab strength than the base shown in Figure 25.

There is no criterion at present to indicate how thick soft limerock bases should be. They are not like the macadams which depend upon the bond between individual stones, nor are they like rigid slabs which have definite beam resistance. They are more or less

FIG. 16.—View showing absence of shoulder and wide, open curb joint on the Tildenville road.

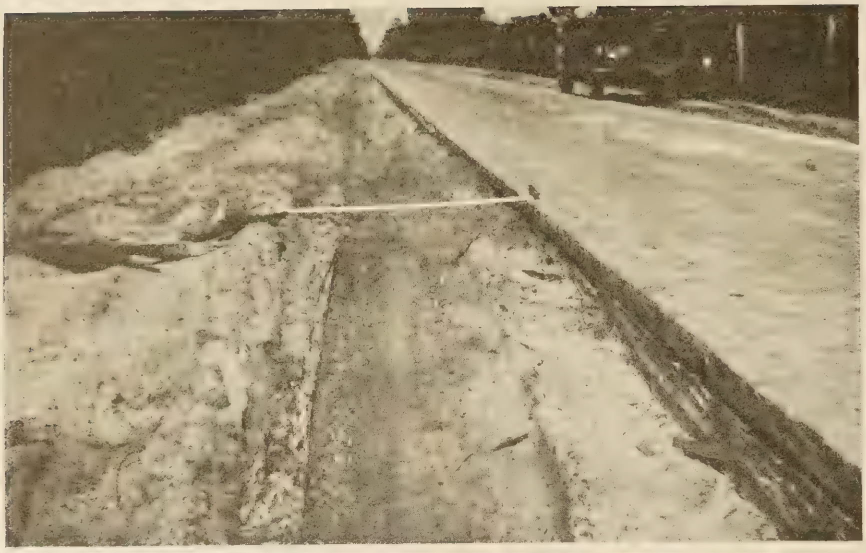


FIG. 17 (LEFT).—SHOWING GOOD CONDITION OF CEMENT-GROUT-FILLED SURFACE NOTWITHSTANDING THE LOSS OF THE SHOULDERS AND WOODEN CURBS.

FIG. 18 (RIGHT).—SHOWING HOW EDGES FAILED WHERE WATER STOOD NEAR THE ROAD SURFACE AND SHOULDERS WERE WASHED AWAY.

FIG. 19 (RIGHT).—THIS BREAK COULD NOT HAVE OCCURRED HAD NOT THE SAND SUBGRADE BEEN DISPLACED.
FIG. 20 (ABOVE).—THE KIND OF TRAFFIC WHICH CAUSED THE DAMAGE.

VIEWS ILLUSTRATING THE DETERIORATION OF THE CEMENT-GROUT-FILLED ORLANDO-BITHLO ROAD AND THE CHARACTER OF THE TRAFFIC WHICH PROBABLY WAS RESPONSIBLE FOR THE DAMAGE.

plastic layers whose function is to confine and utilize the maximum bearing value of the soil rather than to support the load.

Made into slabs, cubes, or cylinders, limerock could meet none of the requirements of concrete. Tests of this character, however, do not indicate the relative value of these materials as Florida pavement bases. Concrete because of its rigidity, expansion, contraction, and warping, can not have uniform and continuous subgrade support and therefore must have beam strength to distribute the load. It fails by cracking and shattering. The action and the function of limerock bases are different. While in themselves they have little supporting value, they at all times retain contact with and make available the maximum subgrade support. If the sand settles slightly the limerock does also, and if proper side support exists the road should be more resistant than before. Failure occurs by excessive settlement, but this can not happen unless the sand base is first displaced. It is possible that if proper side support is supplied a comparatively thin layer of limerock will suffice to prevent loss of sand through the crevices between bricks and to supply additional confinement. Referring to the descriptions of the wider sand-filled roads, it will be recalled that the loose 3-inch brick tops were sufficient to confine the sand subgrade to a remarkable degree, which seems to warrant the above assumption. In the absence of additional side support, a base of considerable thickness will probably be required to carry heavy traffic.

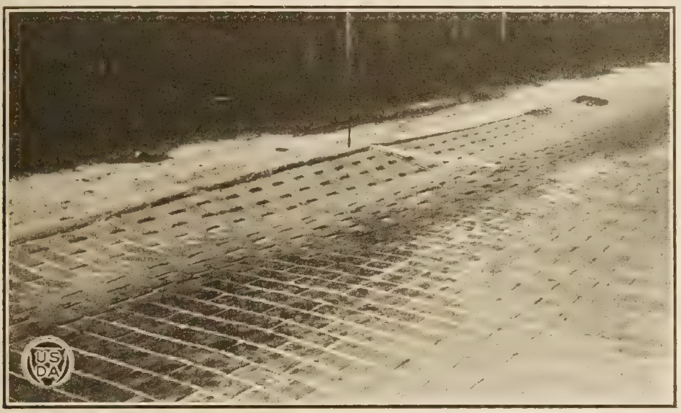


Fig. 21.—Depression in Orlando-Winter Garden road, probably caused by displacement of the sand subgrade, due to vertical movement of the curb.

Fig. 22.—Grooves in Orlando-Winter Garden road which do not impair the smooth riding qualities of the surface.

Fig. 23.—Section of a cement-grout-filled surface laid through a swamp section south of Kissimmee which has conformed to changes in the sand subgrade without becoming rough.

CONCRETE BASES VIEWED AS UNNECESSARY IN FLORIDA.

The use of limerock is warranted only because of the high supporting value of the sand subgrade. If the subgrade support were so low as to require a base course having beam resistance equivalent to that furnished by a 6-inch thickness of concrete, it is questioned whether 10 or even 12 inches of limerock would be adequate.

The behavior of the Florida surfaces, however, has not indicated that such a base is required. Notwithstanding considerable opinion to the contrary, there was ample evidence to show that grooving and settlement were not caused by recent traffic conditions. These defects began to form in many cases soon after completion of the road. In 1918 the grooves on the Orlando-Winter Garden Road had so changed the transverse profile of the surface that the rear wheels of a passing road roller had contact only at their inner edges and thus cracked a number of bricks. The bricks in the Jacksonville-St. Augustine Road rattled during the passage of vehicles in 1918 just as they did in 1923. Naturally, where the roads were entirely neglected, deterioration developed rapidly with increase of traffic, but this was a fault of the organization in charge rather than of the surface.

Fig. 24.—Limerock base before rolling.

Although little could be learned of the traffic which the various roads had accommodated, a most important factor noted was that, to facilitate travel through sand and, in some instances, to comply with traffic regulations, *but few trucks were equipped with other than pneumatic tires.* In this discussion of base courses it is assumed that this type and not solid-tired traffic is to be accommodated in the future. The gross load limitation of the State law is 16,000 pounds on pneumatic-tired vehicles and 8,000 pounds on solid-tired vehicles.

THE VOLUME OF TRAFFIC.

As to the number of vehicles carried, it is indicated by information supplied by the Florida State Highway Commission that between January and June, 1923, considering only trucks, the road between Lakeland and Tampa ranked first, with 200 per day; that be-

FIG. 25.—Failure of limerock base due to washout of sand subgrade. Note the smooth surface obtained by rolling.

tween Orlando and Kissimmee, second, with 169; and that between Sanford and Orlando, third, with 157 trucks per day. The number of trucks averaged from 10 to 30 per cent of the total number of vehicles. Since the road between Lakeland and Tampa carried traffic in two lines, it is apparent that the narrow road between Sanford and Kissimmee received the greater intensity of traffic since it was carried in one line.

Current opinions in regard to the necessary thickness of limerock bases are reflected by the bases employed in present construction. Many of the counties and towns are laying a 6-inch layer, in some instances covered only by a bituminous surface treatment. The Jacksonville-Atlantic Beach Road is being constructed with 7 inches of loose material, or about 5 inches of compacted base. The present Federal-aid specifications require 8 inches. As previously noted, the writer does not believe that a base of uniform thickness is the most economic preventive of the Florida brick road defects. No matter how thick the base is made, the

FIG. 26.—Limerock road compacted by traffic. Laid in 1914.

sides will be relatively weaker than the middle. With few exceptions the condition of the pavements observed indicated that additional shoulder resistance is most essential. There is reason to believe that with a given quantity of limerock, if adequate shoulders are first laid and a confining base layer is made of the material that is left, a considerably more resistant surface will be secured than if all of the rock is used for a base of uniform thickness. On a road 18 feet wide, for instance, a 4-inch base and shoulders 24 by 8 inches will possibly offer greater resistance than a 6-inch base. By this means effective additional road width is also secured.

In those surfaces along which curbs are not used, increasing the width of base with material secured by reduction of thickness is recommended. A base 21 feet wide by 6 inches thick might be more effective under a road 18 feet wide than a base 18 feet wide and 7 inches thick.

The most economic distribution of limerock between base course and shoulders can be determined only by construction and observation of experimental sections. By this means also can be determined the advisability of using wooden curbs when limerock bases and shoulders are employed.

In connection with the use of the limerocks, it is to be emphasized that they must be thoroughly puddled and compacted in order that danger of uneven settlement in the future may be prevented.

FIG. 27.—Limerock road compacted by road roller. Built in 1913 and carefully maintained, it is now a very satisfactory, hard, and compact road.

ROAD MATERIAL TESTS AND INSPECTION NEWS

WATER REQUIRED FOR STANDARD MORTAR CONSISTENCY DETERMINED BY NEW METHOD.

To determine the amount of water required for standard consistency of mortars made with natural sand is the purpose of one of the investigations now being conducted by the physical laboratory of the United States Bureau of Public Roads.

The greatest problem in connection with the strength-ratio test for concrete sands has been that of properly gauging the amount of water for the natural sand mortar for comparison with standard, Ottawa-sand mortar. Each laboratory acts according to its own judgment and, on account of the large personal equation involved, the result has been a wide variation in test results.

Studies made in the bureau's laboratory have included a number of methods such as computation of surface area, determination of point of maximum density, measurement of consistency by the flow table, and various modifications of each of these methods. Lately the problem has been attacked from a new angle in that an effort is being made to determine experimentally the amount of water required to cover the surfaces of the sand grains and to provide for absorption. Knowing this it is only necessary to add cement and the additional water for normal-consistency cement paste to put the mortar in a standard condition.

Briefly, the method is as follows: A representative sample of the sand passing the one-fourth-inch screen and retained on the 100-mesh sieve is dried, weighed, and saturated with water; it is then transferred to a filtering tube of special design and a suction of 15 inches vacuum applied for 10 minutes, moist air being supplied to the sample during suction. The water retained by the sample is determined by weighing. By comparison of this method with the usual method on a number of samples a constant of 1.6 has been found necessary as a multiplier to give an adequate percentage of water for the sand. All material passing the 100-mesh sieve is considered as of cement size and is treated accordingly. The formula is:

$$N = 1.6rW + n\ (C + w)$$

in which

N = required weight of water for mortar mix in grams.

r = percentage by weight of water retained by test of $\frac{1}{4}$–100 sand.

W = weight in grams of $\frac{1}{4}$–100 sand in mortar mix.

n = normal consistency of cement.

C = weight of cement in mix in grams.

w = weight of sand passing 100-mesh sieve in mortar mix in grams.

This method promises to be more reliable than any heretofore tried out, but the amount of data available is as yet not sufficient to form the basis of definite recommendations.

BETTER CONCRETE ROADS.

The conviction prevails that there is room for marked improvement in the methods employed in the construction of concrete roads and the manipulation of the materials used. This view is supported by the results of compression tests on cores drilled from pavements which indicate a wide variation in strength, the maximum being often from 50 to 100 per cent greater than the minimum. A number of factors are known to contribute to the strength of the concrete, but in most instances the cause of defects can not be attributed to any specific deficiency of construction.

It is the common belief that there is great need for the introduction of a more accurate control of the construction process. Certain principles have been evolved through research which are generally accepted. The present problem is one of practically applying these principles to construction. In an attempt to solve this problem, the United States Bureau of Public Roads has in prospect the construction of an experimental concrete pavement cooperatively with one of the Eastern States.

Assuming that the design and specifications are established and that the materials have been selected for the job, the mechanical factors which are frequently neglected and which have an important influence on the resulting concrete are as follows: The accurate measurement of aggregates which involves the bulking of fine aggregates due to moisture content, the correct grading of the coarse aggregate, a uniformly proper consistency and adequate curing of the pavement. With an accurate control of these factors together with certain refinements of construction, it is expected to secure an improved workability of the mixture, a homogeneous concrete of more uniform strength, a smoother riding surface and perhaps an increased yield for a given mix.

In order to obtain a control of this kind and apply it, a study of road-building equipment is being made by the bureau with a view to selecting or modifying available equipment, or devising equipment particularly suited to the requirements. For a more precise means of measuring aggregates a comparison of the weight and volumetric methods is being made. An investigation of the bulking of sand due to moisture content is being conducted with a modern volumetric plant. With regard to the grading of coarse aggregates, consideration is being given to the idea of delivery to the job in screened sizes and combining them at the central proportioning plant. It is also important that some effective means of controlling the consistency be devised.

By means of this experimental construction which is proposed for the coming season, it is hoped to develop the necessary equipment and a practical control of construction which will produce a pavement of better quality and uniformity without adding greatly, if at all, to the cost.

A NOTE ON THE DISTILLATION TEST FOR ROAD TARS.

Considerable variations in the results obtained from this test by different laboratories are caused by the use in some laboratories of uncorrected thermometers, and in others of thermometers calibrated in the vapors of pure substances with known boiling points. The procedure used by almost all producers and State highway testing laboratories for this test is that adopted by the American Society for Testing Materials, serial designation D20–18, which requires that the thermometer shall be set up in the apparatus as in the test, with water, napthalene and benzophenone as distilling liquids. However, the standard method does not state clearly how the temperatures indicated by these calibrations are to be used, and the result has been that only a minority of the laboratories engaged in testing tars make use of this method of determining corrections to be applied to the thermometer in arriving at the true temperature of the distilling vapors. Other laboratories take actual readings of the thermometer as fractionating points. The corrections by the first method may amount to from 5° to 10° at 300° C.

The difference in percentage of total distillate to 300° C. is not a very serious matter, ranging up to 3 or 4 per cent; but when the effect of this distillate on the softening point of the residue is considered, it is often found to be sufficient to place the material tested either within or without the requirements of the specification, depending upon whether a corrected or uncorrected thermometer is used in the test. A variation of 8° or 10° C. in softening point may readily occur.

There are good arguments in favor of either use of the thermometer. The object here is merely to call attention to the influence a variation in practice may have on test results, and point out that its bearing on the interpretation of distillation results and on the selection of specification requirements should be kept in mind. It is obviously desirable that all producers and consumers of road tar products shall agree upon a uniform procedure.

SOFTENING-POINT TEST.

The ring-and-ball method for conducting the softening-point test on bituminous road materials is used by the majority of State testing laboratories, but some States use the cube method in at least some softening-point determinations.

The use of two different methods makes for confusion and lack of uniformity. The universal use of one method is highly desirable, especially in view of the difference in results obtained by the two methods. The committee on tests and investigations of the American Association of State Highway Officials has recommended the use of the ring-and-ball method (see Department of Agriculture Bulletin No. 949, p. 52) and the Bureau of Public Roads in its Typical Specifications for Bituminous Road Materials (Department of Agriculture Bulletin No. 691) stipulates the use of the ring-and-ball method.

TESTING SIEVES.

An effort is being made by the American Society for Testing Materials working in cooperation with the United States Bureau of Standards, United States Bureau of Public Roads, American Association of State Highway Officials, and the several manufacturers, to adopt a practical standard screen scale for testing sieves. Several meetings have been held and enough progress made to indicate that in all probability the screen scale of the United States Bureau of Standards, somewhat modified as to permissible tolerances in both average opening and wire diameter, will be adopted. The general adoption of such a screen scale by all users and manufacturers of testing sieves will greatly simplify the use of the sieves in the laboratory, because it will be possible in all cases to correlate the sieve number with the size of the actual opening and thus definitely fix the size of material under examination.

Should this screen scale be adopted it has been suggested that the Bureau of Standards be requested to furnish sieve correction factors for sieves other than the standard No. 200, in order that anyone who desires to have a sieve calibrated for special purposes can do so

Status of Federal Aid Highway Construction, Bureau of Public Roads, United States Department of Agriculture, as of March 31, 1924

States.	Fiscal years 1917-1923.			Fiscal year 1924.									Balance of federal aid fund available for new projects.
	Projects completed prior to July 1, 1923.			Projects completed since June 30, 1923.			*Projects under construction.			Projects approved for construction.			
	Total cost.	Federal aid.	Miles.	Total cost.	Federal aid.	Miles.	Estimated cost.	Federal aid allotted.	Miles.	Estimated cost.	Federal aid allotted.	Miles.	
Alabama	$3, 789, 011. 74	$1, 794, 703. 21	367. 9	$286, 155. 95	$136, 517. 74	21. 6	$14, 195, 713. 05	$7, 086, 774. 06	897. 9	$652, 035. 75	$278, 708. 11	4. 4	$414, 207. 32
Arizona	6, 518, 025. 52	3, 195, 689. 68	372. 1	786, 232. 63	478, 273. 20	67. 1	2, 692, 535. 69	1, 585, 993. 40	211. 0	476, 241. 20	291, 030. 97	35. 8	891, 710. 19
Arkansas	8, 623, 205. 72	3, 308, 572. 12	736. 2	2, 268, 532. 68	1, 020, 541. 62	186. 5	4, 311, 917. 55	1, 757, 591. 09	229. 6	3, 403, 273. 67	816, 200. 00	195. 5	900, 638. 10
California	8, 495, 547. 60	3, 538, 967. 90	340. 5	2, 964, 861. 97	1, 310, 621. 71	140. 5	11, 771, 123. 33	6, 275, 620. 89	443. 6	808, 281. 23	436, 250. 89	23. 8	3, 066, 853. 83
Colorado	6, 470, 695. 56	3, 136, 238. 67	426. 6	964, 051. 33	531, 160. 80	50. 2	4, 252, 262. 14	2, 299, 496. 02	175. 2	272, 603. 54	152, 983. 61	12. 2	2, 078, 519. 84
Connecticut	2, 568, 643. 95	1, 026, 148. 85	60. 7	128, 610. 43	64, 305. 21	3. 8	1, 877, 498. 46	727, 644. 54	36. 5	1, 270, 571. 00	415, 979. 70	21. 5	671, 602. 79
Delaware	2, 196, 610. 22	621, 154. 83	45. 2	718, 598. 97	317, 815. 00	22. 7	988, 468. 80	389, 767. 50	27. 5	76, 668. 90	31, 961. 10	0. 2	13, 206. 40
Florida	69, 466. 31	29, 700. 63	15. 6	604, 477. 52	288, 175. 17	23. 3	8, 570, 568. 56	4, 228, 785. 06	255. 3	1, 037, 874. 30	440, 221. 40	13. 7	412, 668. 22
Georgia	13, 960, 499. 47	6, 363, 703. 60	925. 5	2, 523, 160. 62	1, 252, 345. 65	255. 7	8, 227, 627. 15	3, 990, 683. 96	686. 1	1, 483, 127. 83	704, 483. 48	103. 7	155, 657. 32
Idaho	6, 880, 673. 73	3, 272, 111. 01	426. 1	828, 865. 25	473, 209. 67	53. 0	1, 666, 084. 06	1, 049, 866. 21	115. 6	678, 769. 61	387, 316. 15	52. 3	558, 510. 95
Illinois	25, 211, 526. 23	11, 414, 291. 96	743. 5	339, 902. 78	166, 739. 78	13. 1	14, 623, 252. 25	7, 277, 387. 20	494. 9	1, 414, 852. 39	698, 013. 63	43. 1	676, 191. 44
Indiana	5, 513, 487. 76	2, 668, 277. 55	157. 0	1, 926, 324. 67	919, 807. 21	64. 4	10, 899, 206. 06	5, 327, 846. 39	345. 7	3, 618, 885. 20	1, 798, 033. 96	146. 4	1, 658, 523. 57
Iowa	16, 040, 079. 62	6, 056, 136. 48	1, 059. 4	4, 779, 027. 83	2, 093, 746. 23	472. 6	7, 559, 578. 44	3, 828, 518. 14	677. 6	2, 763, 109. 43	1, 257, 950. 00	101. 8	21, 537. 82
Kansas	12, 216, 428. 90	4, 248, 438. 34	349. 7	2, 160, 141. 50	741, 151. 46	72. 0	18, 334, 748. 58	6, 530, 966. 77	604. 5	1, 294, 142. 18	577, 646. 46	50. 9	1, 119, 855. 93
Kentucky	6, 620, 289. 80	2, 789, 991. 15	285. 0	3, 892, 469. 01	1, 683, 185. 33	142. 4	7, 514, 885. 23	3, 630, 065. 39	326. 5	471, 726. 68	235, 863. 33	19. 0	621, 049. 35
Louisiana	7, 131, 394. 90	3, 157, 128. 03	590. 4	1, 116, 208. 52	367, 989. 39	54. 2	5, 430, 504. 00	2, 582, 338. 36	355. 9				162, 684. 63
Maine	4, 662, 854. 19	2, 242, 963. 03	159. 8	2, 248, 204. 59	1, 056, 972. 35	70. 9	907, 304. 26	451, 804. 19	34. 8	527, 035. 66	263, 238. 99	26. 9	388, 540. 08
Maryland	5, 309, 394. 94	2, 524, 843. 54	185. 0	1, 427, 449. 75	676, 878. 38	57. 3	1, 601, 912. 79	669, 855. 75	52. 0				141, 427. 32
Massachusetts	6, 841, 975. 16	2, 802, 957. 88	163. 7	1, 045, 304. 51	424, 053. 44	20. 4	5, 223, 923. 29	1, 932, 439. 52	104. 6	1, 603, 248. 87	523, 760. 02	23. 1	1, 146, 762. 92
Michigan	9, 528, 041. 53	4, 343, 817. 14	363. 4	2, 331, 745. 70	963, 110. 18	70. 4	10, 690, 885. 25	5, 230, 876. 33	428. 7	357, 646. 00	178, 022. 50	11. 5	2, 937, 121. 12
Minnesota	19, 828, 671. 37	8, 004, 277. 87	1, 893. 4	4, 208, 889. 87	1, 881, 565. 20	398. 6	7, 294, 164. 82	2, 953, 348. 91	512. 1	456, 531. 47	208, 500. 00	73. 6	149, 820. 46
Mississippi	4, 746, 771. 31	2, 284, 557. 86	462. 4	2, 379, 799. 09	1, 170, 449. 79	128. 5	8, 391, 393. 48	4, 122, 708. 66	535. 6	352, 642. 76	152, 986. 68	27. 8	506, 198. 36
Missouri	5, 272, 757. 08	2, 358, 848. 60	365. 6	5, 120, 381. 37	2, 452, 903. 48	342. 4	14, 599, 273. 33	6, 998, 185. 49	655. 0	1, 430, 832. 46	715, 416. 14	87. 0	2, 991, 348. 54
Montana	7, 935, 185. 30	3, 896, 053. 50	711. 5	789, 664. 09	412, 808. 75	62. 0	1, 847, 534. 34	1, 295, 755. 10	194. 1	1, 123, 265. 98	589, 381. 89	124. 4	3, 227, 934. 57
Nebraska	3, 159, 814. 47	1, 449, 675. 04	475. 6	4, 103, 713. 46	1, 962, 846. 66	821. 7	5, 393, 756. 91	2, 653, 701. 57	696. 3	1, 198, 100. 02	599, 049. 93	132. 0	3, 208, 517. 46
Nevada	3, 049, 109. 29	1, 562, 111. 35	203. 6	486, 806. 51	356, 779. 95	33. 3	3, 563, 552. 53	3, 072, 334. 51	308. 4	400, 982. 30	301, 806. 36	10. 4	649, 665. 58
New Hampshire	2, 336, 997. 00	1, 129, 004. 69	140. 5	728, 350. 97	353, 161. 78	30. 5	603, 215. 61	285, 719. 58	21. 8	238, 984. 11	110, 652. 73	6. 8	190, 800. 21
New Jersey	5, 423, 362. 96	1, 975, 783. 52	112. 1	1, 794, 735. 56	562, 527. 10	29. 4	8, 552, 430. 81	2, 153, 320. 04	49. 0	823, 264. 45	174, 640. 00	10. 9	786, 563. 31
New Mexico	4, 706, 909. 12	2, 433, 663. 68	617. 1	599, 377. 33	325, 186. 00	97. 2	4, 061, 029. 74	2, 519, 288. 58	544. 5	1, 553, 929. 30	1, 019, 519. 32	91. 2	1, 106, 145. 54
New York	9, 826, 633. 82	4, 358, 659. 70	290. 6	4, 552, 518. 80	1, 972, 774. 97	151. 1	22, 208, 222. 68	8, 783, 006. 83	531. 9	8, 690, 700. 00	3, 241, 612. 50	185. 2	4, 688, 988. 14
North Carolina	11, 770, 363. 76	5, 325, 763. 37	826. 8	797, 369. 21	350, 994. 29	57. 9	8, 713, 745. 41	3, 081, 726. 31	233. 2	2, 508, 178. 50	1, 147, 748. 72	68. 1	690, 772. 15
North Dakota	5, 142, 157. 55	2, 492, 599. 09	792. 5	3, 261, 595. 19	1, 614, 534. 18	699. 2	2, 456, 478. 94	1, 183, 150. 78	384. 7	205, 979. 82	102, 989. 89	39. 4	1, 791, 673. 93
Ohio	22, 840, 050. 09	7, 966, 325. 17	662. 8	9, 618, 128. 44	3, 686, 542. 82	281. 0	11, 574, 250. 14	4, 384, 022. 84	310. 2	1, 797, 402. 18	591, 426. 05	60. 5	716, 042. 43
Oklahoma	9, 795, 634. 54	4, 417, 788. 46	371. 5	3, 041, 827. 34	1, 396, 486. 82	121. 3	8, 043, 124. 57	3, 860, 977. 42	354. 9	1, 138, 481. 23	549, 825. 45	56. 7	558, 435. 14
Oregon	10, 391, 362. 48	4, 782, 736. 38	534. 1	1, 368, 500. 56	849, 646. 22	104. 9	2, 963, 118. 99	1, 600, 164. 90	160. 6	138, 208. 95	65, 675. 96	17. 5	31, 105. 39
Pennsylvania	33, 090, 029. 45	12, 615, 058. 79	652. 8	2, 578, 716. 07	1, 054, 171. 61	54. 6	7, 948, 607. 18	2, 699, 782. 50	140. 0	5, 899, 493. 19	1, 622, 725. 00	100. 3	3, 243, 921. 89
Rhode Island	1, 484, 075. 35	647, 634. 96	38. 6	140, 504. 75	61, 669. 36	3. 5	1, 227, 634. 35	481, 683. 13	26. 7				376, 428. 68
South Carolina	6, 181, 485. 41	2, 885, 754. 37	655. 1	1, 790, 048. 23	721, 199. 07	235. 3	6, 460, 068. 45	2, 595, 122. 83	471. 8	694, 554. 49	219, 707. 61	68. 0	211, 733. 95
South Dakota	4, 758, 907. 24	2, 320, 007. 33	534. 5	3, 307, 648. 50	1, 634, 101. 11	393. 4	5, 404, 391. 94	2, 772, 852. 75	669. 5	671, 630. 40	309, 731. 78	61. 7	472, 842. 85
Tennessee	3, 210, 970. 94	1, 535, 762. 18	112. 5	1, 317, 446. 92	647, 258. 24	62. 5	14, 596, 401. 31	7, 109, 466. 98	472. 7	1, 775, 789. 62	654, 004. 29	48. 2	449, 404. 34
Texas	29, 172, 501. 06	11, 094, 069. 77	2, 259. 6	11, 130, 736. 18	4, 209, 946. 93	754. 1	24, 222, 455. 38	9, 701, 177. 66	1, 495. 8	4, 036, 658. 84	1, 602, 881. 78	277. 0	705, 967. 10
Utah	2, 175, 007. 41	1, 196, 437. 68	116. 6	804, 952. 96	461, 959. 20	76. 7	3, 631, 445. 27	2, 272, 865. 38	249. 4	716, 980. 03	531, 949. 40	39. 1	805, 519. 44
Vermont	1, 370, 715. 63	669, 433. 75	53. 1	198, 959. 70	99, 240. 82	6. 8	1, 474, 576. 24	721, 509. 24	47. 6	290, 856. 75	128, 848. 50	6. 5	549, 321. 42
Virginia	6, 823, 978. 36	3, 279, 029. 56	402. 5	2, 081, 874. 91	968, 191. 98	94. 7	9, 009, 188. 44	4, 247, 927. 51	334. 7	911, 299. 18	270, 025. 88	45. 5	379, 215. 52
Washington	10, 356, 980. 82	4, 819, 105. 70	419. 8	618, 239. 13	273, 551. 37	35. 4	2, 354, 341. 13	1, 110, 300. 00	97. 0	398, 953. 23	194, 500. 00	14. 7	375, 912. 76
West Virginia	4, 100, 225. 73	1, 800, 932. 41	206. 3	1, 276, 510. 70	511, 859. 12	42. 2	4, 844, 949. 70	2, 136, 366. 50	163. 9	485, 387. 10	216, 228. 55	19. 0	290, 469. 95
Wisconsin	15, 504, 691. 39	5, 996, 989. 24	1, 077. 6	1, 923, 159. 81	856, 321. 21	153. 1	3, 970, 457. 96	1, 857, 167. 49	206. 3	109, 324. 13	54, 662. 06	9. 3	3, 035, 710. 68
Wyoming	4, 601, 439. 36	2, 210, 774. 20	534. 8	990, 072. 46	582, 755. 04	102. 7	4, 028, 357. 61	2, 484, 621. 96	281. 2	243, 934. 58	56, 705. 52	35. 5	416, 122. 15
Total	407, 704, 641. 14	174, 044, 673. 82	23, 297. 2	104, 345, 854. 32	46, 398, 032. 59	7, 236. 1	340, 778, 161. 20	155, 992, 576. 22	16, 652. 4	60, 502, 438. 51	24, 920, 866. 29	2, 602. 1	50, 643, 851. 08

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost, $62,976,042.25; federal aid, $27,799,234.86; miles, 2,885.2.

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.
*Report of the Chief of the Bureau of Public Roads for 1922. 5c.
*Report of the Chief of the Bureau of Public Roads for 1923. 5c.

DEPARTMENT BULLETINS.

No. 105. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136. Highway Bonds. 20c.
220. Road Models.
257. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314. Methods for the Examination of Bituminous Road Materials. 10c.
*347. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370. The Results of Physical Tests of Road-Building Rock. 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. 35c.
407. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*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. 10c.
*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. 5c.
*724. Drainage Methods and Foundations for County Roads. 20c.
*949 Standard and Tentative Methods of Sampling and Testing Highway Materials, Recommended by the Second Conference of State Highway Testing Engineers and Chemists, February 23 to 27, 1920, 25c.
*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.

DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.

FARMERS' BULLETINS.

No. 338. Macadam Roads.
*505. Benefits of Improved Roads. 5c.
597. The Road Drag.

SEPARATE REPRINTS FROM THE YEARBOOK

No. *727. Design of Public Roads. 5c.
*739. Federal Aid to Highways, 1917. 5c.
*849. Roads. 5c.

OFFICE OF PUBLIC ROADS BULLETIN.

No. *45. Data for Use in Designing Culverts and Short-span Bridges. (1913.) 15c.

OFFICE OF THE SECRETARY CIRCULARS.

No. 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.
*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.
161. Rules and Regulations of the Secretary of Agriculture for Carrying out the Federal Highway Act and Amendments Thereto.

Public Roads 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, January 1 to July 1, 1921.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH.

Vol. 5, No. 17, D- 2. Effect of Controllable Variables Upon the Penetration Test for Asphalts and Asphalt Cements.
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. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

*Department supply exhausted.

WASHINGTON : GOVERNMENT PRINTING OFFICE : 1924

FUNDAMENTAL PRINCIPLES OF HIGHWAY FINANCE

The wide variation in the present status of highway development in the several States prevents the adoption of a uniform policy for securing the funds necessary to the annual highway budget and expending these funds. Generally speaking, however, these principles may be enunciated.

(*a*) States in the initial stage of highway development should issue bonds to defer that portion of the annual charge for construction which would overburden either property or the road user.

(*b*) States where original construction programs are well under way can, in the main, finance further expenditure for construction by bond issues devoted to deferring the cost of special projects.

(*c*) States where original construction is practically completed are concerned chiefly with maintenance and reconstruction and should depend on current funds, save in cases of emergency.

(*d*) The maintenance of interstate and State roads should be a charge against the road user.

(*e*) Roads serving a purely local purpose will generally require only light upkeep, and this should properly be a charge against the adjacent property, which in this case is the first and often the only beneficiary.

(*f*) No road should ever be improved to an extent in excess of its earning capacity. The return to the public in the form of economic transportation is the sole measure of the worth of such improvements.