# PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

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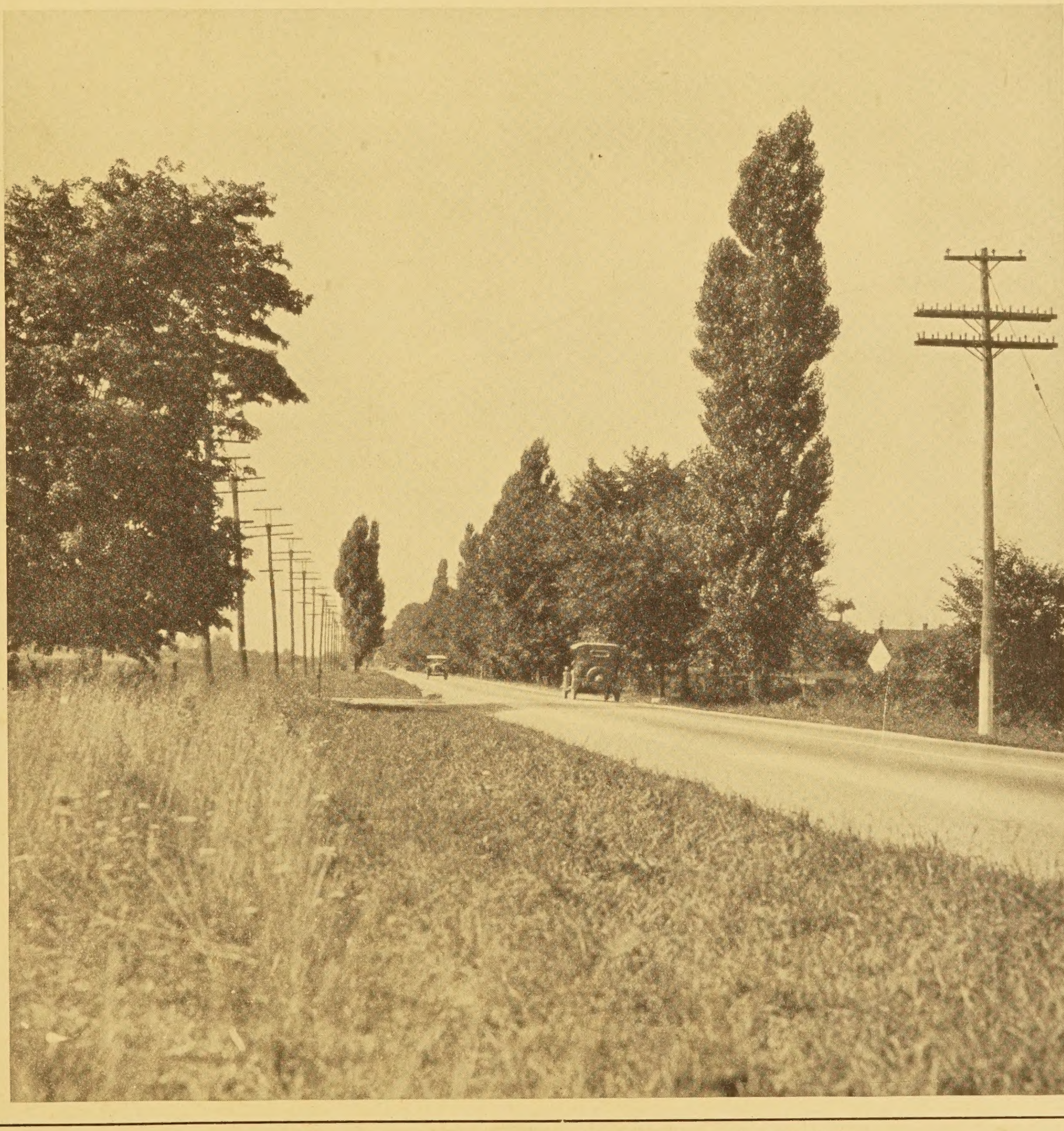

Pennsylvania Federal-aid Project No. 8c, a Concrete Highway

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## TABLE OF CONTENTS



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# THE SUPPORTING VALUE OF SOIL AS INFLUENCED BY THE BEARING AREA

By A. T. GOLDBECK and M. J. BUSSARD, United States Bureau of Public Roads

WHEN a given unit of load is applied to a soil over various areas, the depth of penetration is directly proportional to the square root of the area over which the load is applied. This relation has been established independently and practically simultaneously by experiments conducted in June, 1923, by the Bureau of Public Roads at the Arlington Experimental Farm, Arlington, Va., and by A. Bijls, chief of highways and bridges, of Belgium. The test conditions under which this relation has been established have necessarily been restricted and the applicability of the relation to more general conditions remains for further investigation.

By the use of formulae or diagrams expressing the established relation it is possible within limits to predict or determine from a knowledge of the penetration of any given unit load, applied experimentally over a given area on any soil, the penetration which will result from the application of the same unit load to any area of the soil, provided the penetrations involved be small enough to permit the supporting mass to act for the most part elastically.

The application of such a relation to the design of roads and more particularly to the design of footings of bridges and other structures is obvious. Its use should make possible a more certain design of footings and should be especially helpful in the prevention of unequal settlement of all kinds of structures.

The facts discovered indicate that such unequal settlement is likely to occur as the result of methods of footing design, heretofore followed universally, in which the areas of the footings under various parts of a structure are predicated upon the delivery of a uniform unit load to the soil regardless of the areas of the footings. The indications are strong that this practice is erroneous; and it has apparently been positively proved that, in its place, a method should be adopted which, based upon this observed relation of penetration and area, assures equal penetration instead of equal unit load.

The general form of the relation expressed mathematically is:

$$\frac{p}{P}=\sqrt{\frac{a}{A}}$$

in which, $p$ and $P$ are the penetrations resulting from the application of a constant unit load to areas $a$ and $A$.

The above relation was established experimentally and was also developed mathematically on the assumption that for any particular soil, the areas under pressure at different depths are confined within lines of like inclination extending from the boundaries of the bearing areas.

### DESCRIPTION OF EXPERIMENTAL METHODS

Since soils exist commonly in the nature of semifluids, deforming in part elastically yet yielding under the continuous application of load, it is necessary, in order to establish a basis of comparison between the supporting value of different areas, to study their behavior in one of two ways; (1) by observing the relative loads necessary to produce common penetration; or (2) by observing the relative penetrations caused by the same unit of load.

The latter method was used in the experiments of the Bureau of Public Roads; and a criterion for the measurement of supporting value was arbitrarily assumed as the unit of load which would cause a bearing block 9 square feet in area to penetrate the soil 0.1 inch.

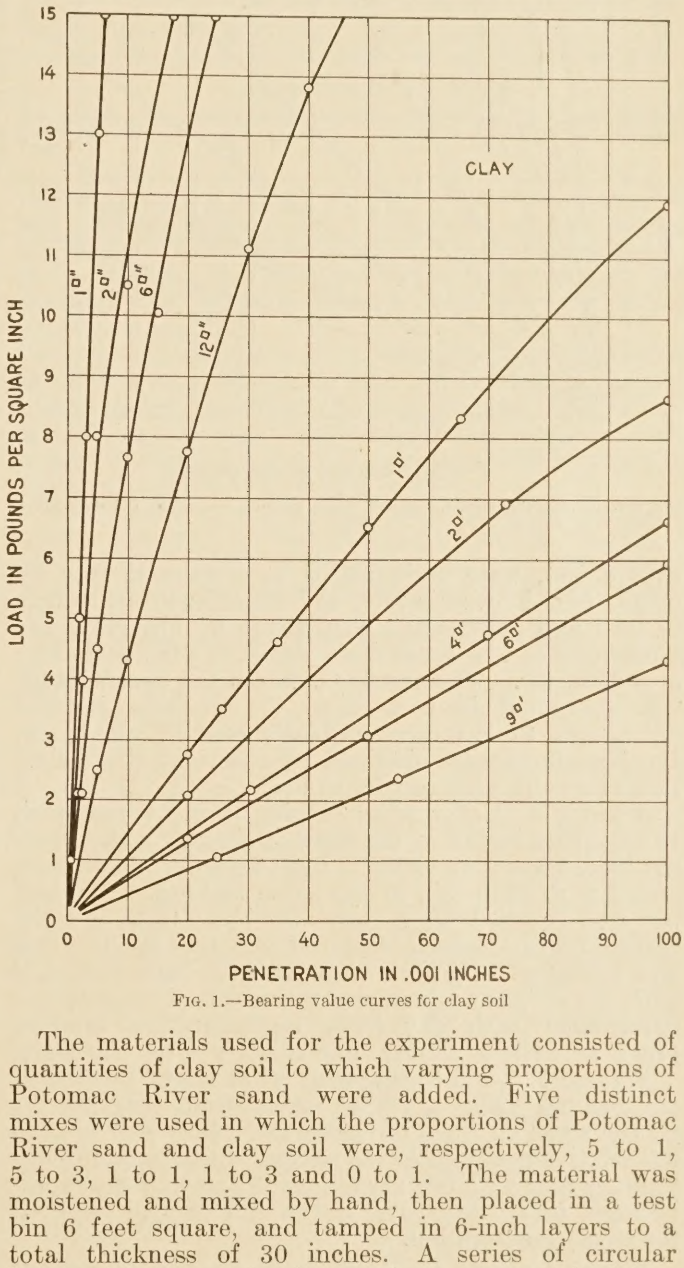


FIG. 1.—Bearing value curves for clay soil

The materials used for the experiment consisted of quantities of clay soil to which varying proportions of Potomac River sand were added. Five distinct mixes were used in which the proportions of Potomac River sand and clay soil were, respectively, 5 to 1, 5 to 3, 1 to 1, 1 to 3 and 0 to 1. The material was moistened and mixed by hand, then placed in a test bin 6 feet square, and tamped in 6-inch layers to a total thickness of 30 inches. A series of circular bearing blocks ranging in area from 1 square foot to 9

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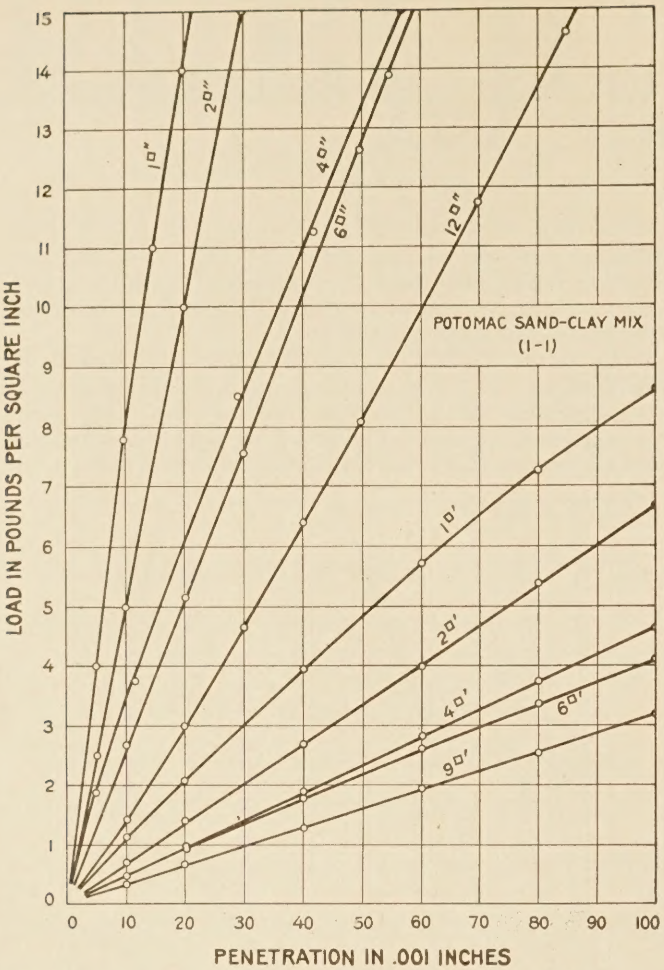


Fig. 2.—Bearing value curves, clay soil mixed in equal parts with Potomac River sand

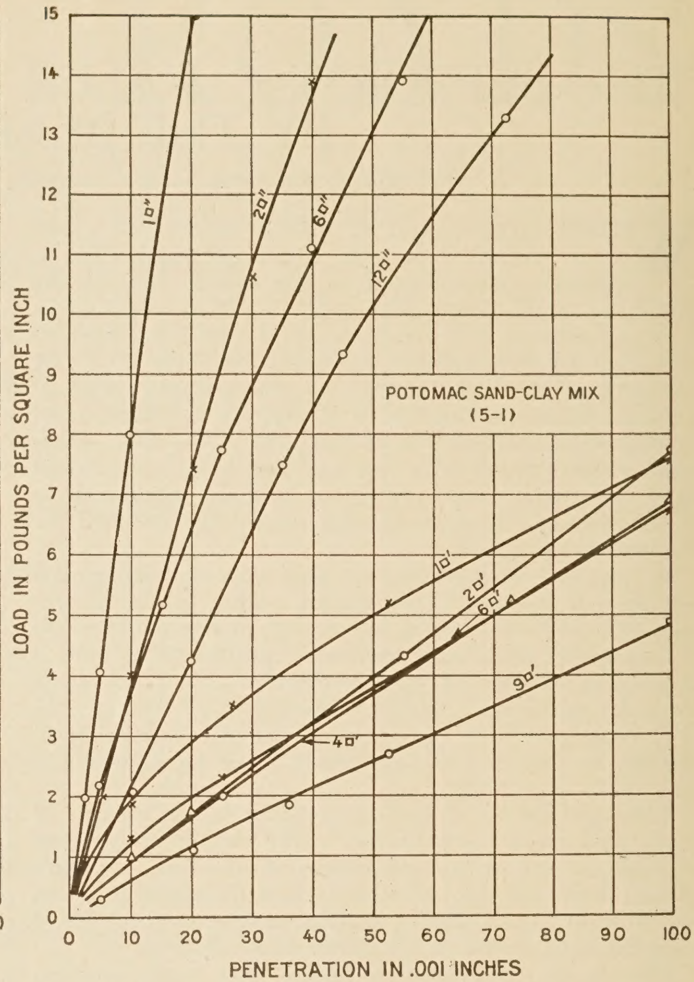


Fig. 3.—Bearing value curves for Potomac River sand and clay soil mixed in proportion of 5 to 1

square feet, were each loaded at a uniform rate by means of a hydraulic jack and simultaneous readings of load and penetration were made by observing the movement of two Ames dials placed at each extremity of a diameter. The average between the two readings was computed in each case, to eliminate possible errors due to the uneven penetration of the block. Load readings were obtained by observing the deflection of a calibrated resistance beam.

A series of smaller areas ranging from 1 square inch to 12 square inches in the form of circular metal bearing blocks was also tested. Both series of blocks were tested with each mix in the same manner. The test bin was emptied after each individual test, and the material was loosened, replaced and retamped. This was repeated a number of times with each area and with the different mixes, and the moisture content was determined each day from representative samples taken at various depths, immediately after the tests.

Figures 1, 2 and 3, represent what might be termed the bearing value curve or stress-strain diagram for all the areas on three of the mixes. It is well to note the relative positions of the curves, which undoubtedly indicate that with few exceptions the smaller the superimposed area, the greater is the unit of load required for equal peneteration.

Figure 4 shows the total loads applied to various areas, which produce a common penetration of 0.1 inch. The curves in the upper portion of the figure show that the unit of supported load increases as the superimposed area decreases for a given penetration.

The algebraic equations of the curves were derived in every instance, the reason being that there was necessity for a means of identification and comparison between the behavior of the various areas when used with different mixes. It is seen, however, that they are all of the same general type, differing in their constants, owing to the difference in compaction, moisture content, state of preparation, etc.

### THE RELATION OF PENETRATION AND AREA UNDER CONSTANT UNIT LOAD

Since those in charge of the tests were at the time concerned with the load causing a penetration of 0.1 inch for an area of 9 square feet, and contemplated that this investigation would make it possible to obtain this information by means of tests performed with a bearing block of small area, it was necessary to analyze the data from a different point of view, namely, by considering the relative penetrations of the areas produced by a constant unit of load, the unit of load in each case being that which caused 0.1 inch penetration when applied to an area of 9 square feet. Therefore curves similar to Figure 5 were plotted from data obtained on each mix. Since they were found to be of similar type, the existence of an unknown general relation was suspected. Consequently, the curve shown in Figure 6 was developed from the average of the five individual curves. It is evident from this average curve that

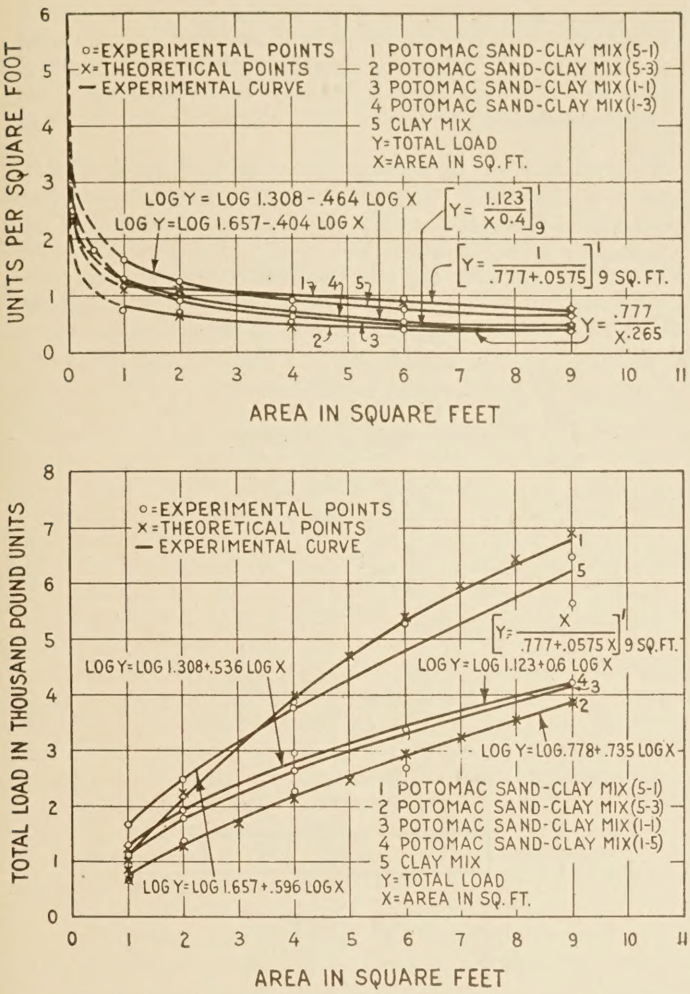


FIG 4.—Total and unit loads required to produce common penetration of 0.1 inch under different areas on various soils

under a constant unit of load the penetration decreases very rapidly as the area decreases, apparently according to some determinate and continuous mathematical function.

The curve of experimental results shown in Figure 6 by the dotted line is very closely approximated by a parabola shown by the solid line whose general equation is

$$y = ax^2$$

where $y$ = area of bearing block in square feet
$x$ = penetration in inches
$a$ = a constant which depends upon the penetration of a given size of bearing block. In the present analysis the relation is based on the penetration of a 9 square foot block to a depth of 0.1 inch. For this condition $a$ becomes 900.

The relation between area of bearing and penetration, for a constant unit load, corresponding to that which causes a 9 square foot area to penetrate 0.1 inch is thus expressed by the following equation:

$$y = 900\ x^2$$

For the conditions of this test it is apparent that the penetrations of several areas are proportional to the square roots of the areas. Necessarily, the tests have been limited to a range of bearing areas which does not include the larger areas encountered in structures, the

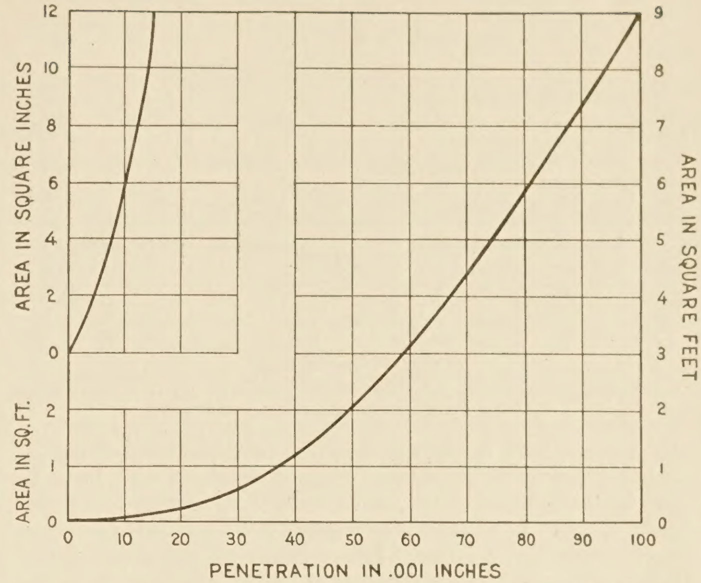


FIG. 5.—Typical curve showing penetrations of various areas when loaded with the unit lqad which caused penetration of 0.1 inch when applied to area of 9 square feet

largest area used being 9 square feet; moreover, the soil was confined within a bin. The above relation having been established for the range of areas and test conditions as noted, it will be interesting to investigate the possibility of this same relation holding true for other areas and conditions.

Curves showing the distribution of earth pressures through a sand fill due to load application on bearing blocks placed on the top of the fill will shed light on the possible reason for the above relation and will also furnish the basis for assumptions which will be made in the development of a general theory.

The curves in Figure 7, drawn from experimental results obtained by the Bureau of Public Roads in 1917,[1] illustrate the variation in pressure distribution at various depths below the area of load application.

[1] See 1917 Proceedings of the American Society for Testing Materials.

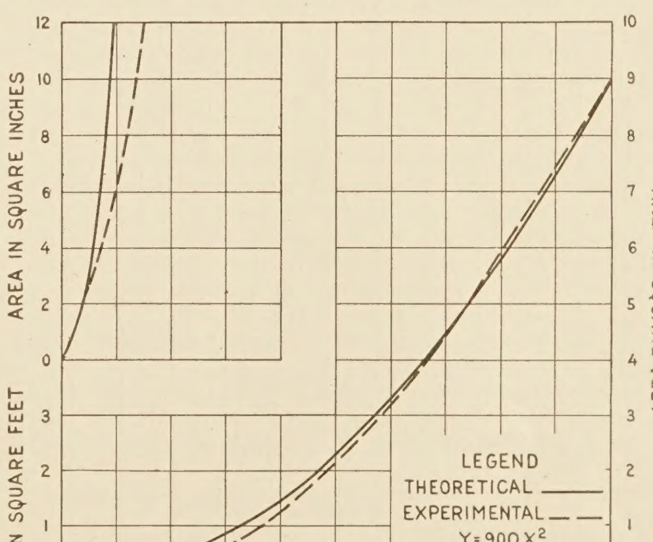


FIG. 6.—Comparison of experimental and theoretical curves

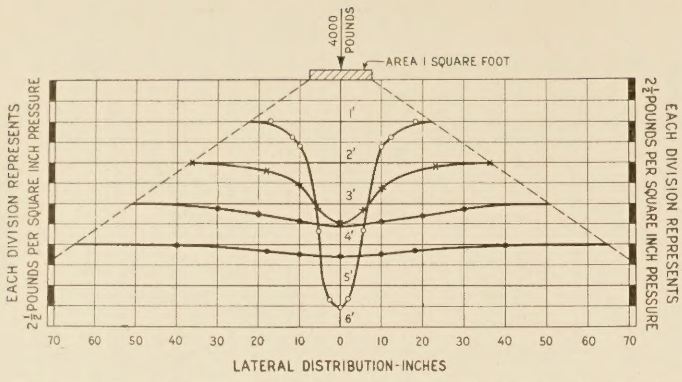


FIG. 7.—Lateral distribution and intensity of pressure in soil at various depths resulting from the application of load to the surface

In Figure 8 it is shown that at any particular depth the intensity of pressure is dependent on the area of the bearing block used, and, in fact, it seems to be the case that the maximum intensity of pressure at any given depth is in direct proportion to the area of the bearing block. It is therefore quite evident that the curves of distribution of pressure are similar for different areas, though of different magnitude and different distribution, depending on the area of load application. It is also quite evident that for like intensities of pressure applied to different areas, like intensities of pressure within the soil due to the loads on those areas will be attained at different depths in the soil, a large block compressing a greater depth of soil through a given range of pressure intensities than a small block. From this consideration it follows that for corresponding pressure intensities on blocks of different areas a

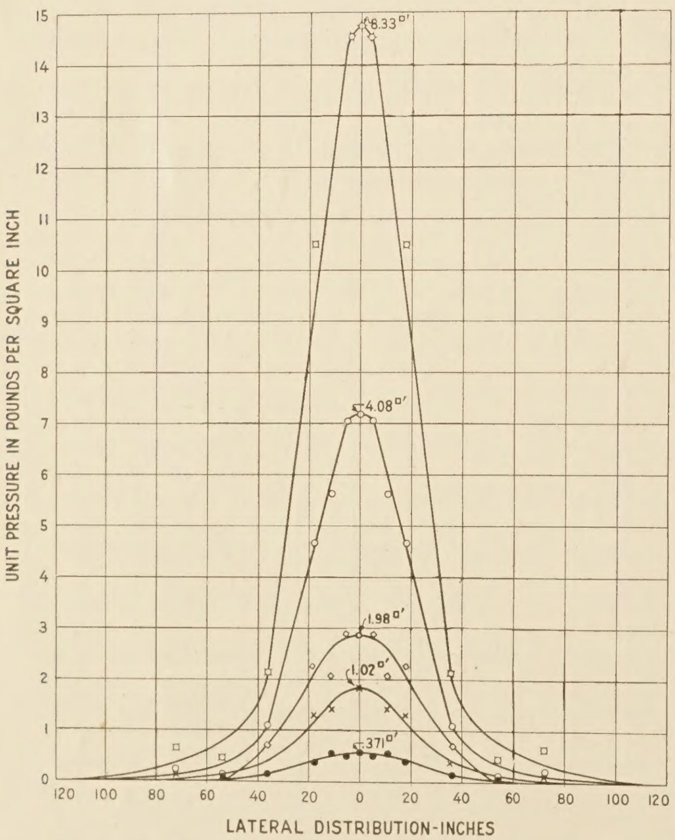


FIG. 8.—Lateral distribution and intensity of pressure resulting at the same depth from application of a constant unit load of 4,000 pounds per square foot to bearing areas of several sizes

large bearing block must depress the soil more than a small block. In Figure 7 it is seen that the layers under compression at different depths below the bearing block are confined approximately between lines radiating downward from the boundary of the bearing area.

In Figure 9 we have two areas, $A$ and $a$, each subject to unit load $P$. Assume that the actual curves of pressure in the soil beneath these areas are replaced by equivalent uniform pressures confined within areas as indicated. Let $P_1$ be the intensity of pressure produced on area $a_y$ at depth $y$ by area $a$. Also let $y_1$ be the depth to area $A_{y_1}$ where the intensity of pressure produced by $A$ is equal to $P_1$. Then, since reactions at any depth must equal applied loads,

$$Pa = P_1 a_y \text{ and } PA = P_1 A_{y_1} \text{ or}$$

$$\frac{Pa}{PA} = \frac{P_1 a_y}{P_1 A_{y_1}} \text{ or}$$

$$\frac{a}{A} = \frac{a_y}{A_{y_1}}$$

By similar triangles—

$$\frac{r}{R} = \frac{y_r}{y_R} = \frac{y}{y_1} \text{ or } y_1 = y\frac{R}{r}$$

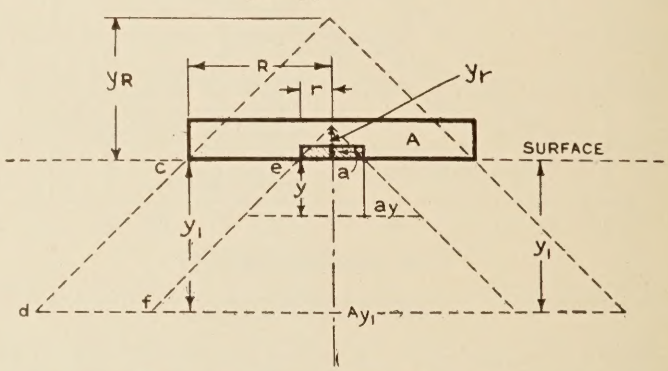


FIG. 9.—Diagram showing distribution of pressure from two bearing areas and depths to planes of equal pressure intensity

Assuming a constant modulus of elasticity, $E$, the total deformation, $e$, of a column of soil of length $l$ at unit stress $S$ is expressed as follows:

$$e = \frac{Sl}{E}$$

Applying this relation to the problem in hand, since the total deformation must be the penetration of the bearing blocks in any case, the ratio of total deformations or penetrations under bearing blocks of the two areas assumed must be:

$$\frac{e_a}{e_A} = \frac{\frac{Sy}{E}}{\frac{Sy_1}{E}} = \frac{y}{y_1} = \frac{y}{y\frac{R}{r}} = \frac{r}{R} = \frac{\sqrt{a}}{\sqrt{A}}$$

That is, the relative penetration of the two areas is equal to the ratio of the square roots of the areas for like intensities of pressure on the two areas. Although the above analysis is not exact, it at least tends to show a strong probability that the law which seems to be followed by the bearing areas tested may be extended to areas of any size.

(Continued on page 8.)

# HIGHWAY RESEARCH BOARD PROCEEDINGS

## FOURTH ANNUAL MEETING HELD AT WASHINGTON IN DECEMBER

By J. L. HARRISON, Highway Engineer, United States Bureau of Public Road

THE fourth annual meeting of the Highway Research Board was held at Washington, D. C., December 4 and 5, 1924. Dr. Vernon Kellogg, permanent secretary of the National Research Council, in the address of welcome announced that the purpose of the Highway Research Board is to affect much needed correlation in highway research and to disseminate information in regard to the results of such research.

Comparing the development of the modern dye industry the phenomenal progress of which has been based upon scientific research with the slow progress that has been made in certain other industries and arts, such as ceramics, in which reliance has been placed upon rule-of-thumb methods, he sounded the keynote of the board's sessions when he stated emphatically his firm belief that research yields large dividends in actual dollars and cents and that both economy and progress depend upon it.

Thomas H. MacDonald, chief, Bureau of Public Roads, one of the directors of the Highway Research Board, discussed the financial value of highway research, pointing out that a discussion of such a topic ought to introduce a note of practical application of those scientific principles and facts, which we arrive at through research and through investigation, and bring out their actual value in dollars and cents to the people of the United States.

That it does actually have such a value he illustrated by a number of examples. One of these—the use of the thickened edge in the design of concrete roads—which is the result of an extended research, makes possible a saving of about 390 cubic yards of concrete per mile. At $10 a cubic yard this is a saving of $3,900 per mile. There are 24 States that have adopted this new design. If, in these States, 2,400 miles of concrete roads are constructed each year, the saving effected amounts to $9,360,000. Other equally important savings from improved design will follow, Mr. MacDonald stated, as research work is developed.

Another case in which it is known that decided savings have resulted from highway research is the intensive laboratory research by which the Iowa Highway Commission has been able to develop means of appropriately using nonstandard aggregate in concrete construction. In building approximately 75 miles of concrete pavement during 1920 and 1921, $155,638 were saved to the State through the successful work of its laboratory. Such savings can be made in many States if the attention of their laboratories is turned toward research work.

Another phase of the value of highway research is presented in the construction field. At present there is a common feeling that engineers are crowding many highway contractors to the wall. It is the duty of highway engineers to analyze this attitude and take steps to overcome it. But this can be done only through research—research particularly in the construction field.

Mr. MacDonald pointed out the causes which have been found to prevail where there has been unsatisfactory progress on Federal-aid road work, of which the two most important were: weather, 33 per cent; and management, 27 per cent. He presented graphs showing how contractors lose money on such operations as wheel-scraper work and how effective rather simple suggestions can be in helping contractors to do their work more effectively. In one case cited the cost of grading work was reduced more than 20 per cent through suggestions that it was possible to make to contractor as the result of research in the construction field.

"In my judgment," said Mr. MacDonald, "the whole story in profitable and unprofitable highway contracts lies in that operation, and it seems to me that in this field the research agencies have an opportunity not only of helping the contractors who are building our roads to increase their profits, and the quality of their output, but actually to decrease the cost of highways to the public. When we are spending in this country each year a billion dollars or more for highway construction and maintenance, is it necessary to develop any farther the enormous financial value of highway research when, on a single operation a saving of between 20 and 25 per cent can be made by the use of stop watches and the analysis of the causes of delays and how to avoid them?"

In rendering his report, Charles M. Upham, director of the Highway Research Board, drew attention to the fact that economy in the construction and maintenance of highways is necessary but that economy does not mean spending less money or restricting highway development. Rather it is to be attained by making more complete use of advanced ideas in methods, practices and designs as these are developed through research and investigation. Emphasis was laid on the fact that one reason for the common failure to bring highway construction and maintenance practices into more complete harmony with the results of completed researches is the fact that as presented to the profession these are commonly accompanied by such a mass of supporting data that the busy executive finds it difficult to give them the study they deserve. Data published in the form now commonly used are valuable. But, in the interest of economy, they should also be presented in condensed summary reports. Such reports would summarize the important facts of the fuller reports, but would give sufficient details to afford a proper understanding of the results. Perhaps the obstacles that now interfere with the spreading of knowledge of research work might be overcome by the publication of consolidated and condensed reports by the Highway Research Board acting in cooperation with other agencies. The large losses in the highway field which can be traced to an incomplete dissemination of information with regard to the results of important researches emphasize the value of such a service.

### REPORT OF COMMITTEE ON ECONOMIC THEORY OF HIGHWAY IMPROVEMENT

In representing his report, Prof. T. R. Agg, chairman of the committee on economic theory of highway improvement, touched on the scope of the committee's work, and drew attention to the fact that research in this field involves studies of the road surface and the cost of operating vehicles. The determination of economic relationships must include studies of the cost of constructing and maintaining each type of surfacing, as well as the cost of operating traffic over it.

The cost of operation has to be reduced for study to the factors entering into it, such as the wear and tear on the vehicles used, gasoline and oil consumption, tire wear, etc. In turn, gasoline and oil consumption are affected by the rolling resistance which must be overcome by the engine in driving the car. Test results show a variation of from 20 to 700 pounds per ton in rolling resistance at a speed of 10 miles an hour. Except on a smooth pavement, at slow speeds, there appears to be no important difference in rolling resistance between low pressure tires and standard tires. Gasoline consumption may also be affected by gradient. Experiments show that the rate of tire wear is affected by the type of surfacing. It also appears to be affected by the amount of inflation.

By such studies as those on which reports have been rendered, as here briefly referred to, and those under way or proposed, a considerable body of data on the cost of operating traffic on various types of surfacing is being built up.

### COMMITTEE ON STRUCTURAL DESIGN OF HIGHWAYS

A. T. Goldbeck, of the United States Bureau of Public Roads, chairman of the committee on structural design of highways, submitted his report in several sections, the first of which dealt with the various investigations in progress in connection with the determination of the characteristics of subgrade soils and the development of methods of improving bad subgrades.

*Subgrade investigations.*—It is believed that the introduction of such granular materials as sand, gravel, cinders, etc., in the subgrade not only tends to reduce the capillary tension in the subgrade soil but allows condensed moisture to be deposited on a subgrade made up of materials the bearing value of which is not so greatly decreased by moisture, but as yet no very definite relation has been determined between capillary moisture, as determined in the laboratory, and the maximum moisture content which may be found in the subgrade under a pavement.

*Design of concrete slab.*—The conclusions from a rather elaborate series of tests on the effect of static loads on road slabs were presented. Among the more important facts brought out, the following appear:

Plain concrete of 1:3:6 mix offers resistance to impact ranging from about 60 per cent to 80 per cent of that developed by plain concrete of 1:1½:3 mix. In all cases the slabs tested appear to offer a greater resistance to impact than to static loads.

From the studies of motor truck impact, it appears that little impact is developed by pneumatic tires even on rough granite block pavements. Solid tires, on the other hand, develop stresses ranging from 200 to 500 per cent and more of the static load stresses. Cushion tires, depending on their design, develop impact stresses intermediate between those developed by pneumatic tires and those developed by solid tires.

The tests made on skew arches show that higher reaction stresses will exist at the obtuse angle end of the abutment than at the acute angle end. Some idea of the variation in stress between the two ends of the abutment can be had from the fact that for a 60 degree skew arch both the horizontal and the vertical reactions at the acute angle end are practically zero.

*Fatigue in concrete.*—An extended paper on the fatigue of concrete was presented by Dr. W. K. Hatt of Purdue University. The divergency of opinion which has existed as to the elastic limit of concrete was noted and discussed. The conclusion drawn was that this divergence is probably due to the use of imperfect instruments, to the age of the samples tested and to the amount of moisture present in the samples. For tests in this field the use of concrete which has aged from nine months to a year was recommended.

The investigations of fatigue which were reported indicate that for specimens over six months old the endurance limit under repeated stress is about 55 per cent of the static load capacity. Specimens aged 28 days can not be depended upon to have an endurance limit of over 40 per cent. Rest periods do not appear materially to affect the fatigue limit of well-cured concrete. Stresses above the fatigue limit cause progressive deterioration. From this it would appear to be desirable to so design concrete highways that the maximum loads which they must carry will cause maximum fiber stresses not to exceed 50 per cent of the modulus of rupture.

### COMMITTEE ON HIGHWAY FINANCE

H. R. Trumbower, of the Bureau of Public Roads, chairman of the committee on finance, stated that, in considering highway finance, one of the first problems which arises is the selection of an appropriate basis for the apportionment of the cost of construction and maintenance among those benefited directly and those benefited indirectly. This leads at once to a study of motor vehicle traffic and the taxes now imposed on this traffic. Of these, the license fees and the gasoline taxes go almost entirely into the highway funds and, for 1924, are expected to provide one-third of the money expended on construction and maintenance. This proportion is considerably greater than it was in 1921 when only about one-seventh of the money expended on highway construction and maintenance was collected in this way and this increase indicates the prevailing tendency toward the levying of heavier taxes on motor vehicles. To determine whether this tendency is proper and should be encouraged will require investigation in such fields as the effect of improved roads on adjacent land values, relative use of city streets and rural highways, personal property taxes on motor vehicles, etc. Only after careful studies in these and in related fields will it be possible to determine whether the present scheme of taxing motor vehicles makes for a thoroughly equitable and satisfactory distribution of taxes among those benefited.

In his discussion of highway finance Frank Page, chairman of the North Carolina State Highway Commission, presented an interesting analysis of contracts defaulted in North Carolina. On a $75,000,000 construction program involving 700 contracts, 35 failures involving 21 contractors have been recorded. Nineteen of these 34 contracts were in the hands of contractors devoid of experience. They had practically no equipment which, of course, means that they had no funds. Five of the contractors had experience but had failed in other States and so had come to North Carolina without funds. Six of the failures were due to neglect of business. Two of the contracts were in the hands of "ordinary, everyday crooks" who "went onto the job with the full determination to milk it." The last two failed because they underbid.

Mr. Page expressed the view that more care should be exercised by the companies bonding contractors. The present practice of making the premium large enough to enable bonding companies to carry losses of this sort is unfair to the good contractors and unfair to the State.

A lively discussion followed the presentation of this paper indicating that the present practices in regard to selecting risks, calculating premium rates, and taking care of defaults involve many problems which deserve careful and thoughtful investigation.

#### REPORT OF COMMITTEE ON HIGHWAY TRAFFIC ANALYSIS

G. E. Hamlin, of the Connecticut Highway Commission, chairman of the committee on highway traffic analysis, stated that the automobile saturation point is a matter of great importance in the determination of future traffic, but added that it appears that this point can not be determined on the basis of any existing data.

The importance of a study of the question of adequate rights of way to protect future traffic developments was urged. "Bottle-neck" points on existing highways often cause a reduction in traffic-carrying capacity. Highway engineers should study and eliminate these. Minimum speed laws are needed to develop the full capacity of highways. The probability that the larger part of the accidents occurring outside of urban districts are directly chargeable to slow-moving vehicles is another reason for suggesting minimum speed laws for heavy-traffic roads. More attention to the relation of the highway wearing surface to traffic needs was stressed. Many miles of wearing course capable of carrying traffic 365 days in the year are needed rather than a few miles of high-class pavement.

The purpose of highway transport surveys was discussed. These should (1) determine daily, seasonal, and yearly traffic and its distribution over the State, (2) estimate future traffic, and (3) show the relation of traffic to traffic factors. From the data so secured highways should be classified and appropriate widths for the various classes developed.

The discussion was led by John N. Mackall, chairman and chief engineer of the Maryland State Roads Commission. Mr. Mackall invited attention to the following quotation from Wellington, "* * * the distorted preeminence given by engineers * * * to the pettiest details of how to build the separate works which go to make up a highway, to the neglect of the larger questions of where to build and when to build and whether to build at all, has in it something that is at once astonishing and discouraging * * *." The real test for a highway transport study, said Mr. Mackall, is: "Does such a survey furnish road authorities with data that assist in the proper location and design of new highways?" To meet this need fully, traffic studies should develop rating curves from which to determine the relative meaning of coincident and subsequent traffic counts. Such curves would form an adequate basis for determining maintenance cost fluctuations and would serve as the first step in solving the larger problem of making dependable estimates of traffic to be expected on proposed improvements.

The second step in answering the larger questions of when to build, where to build and whether to build at all, questions which must be answered if real economy is secured in the development of any large highway program, involves the determination of how the traffic is likely to be affected by those factors known to affect traffic. Most of these factors, such as the proximity of large cities, manufacturing enterprises, points of historical interest, touring, etc., are well recognized but no rules for determining their effect on the traffic on proposed highways have, as yet, been developed.

Finally, rational rules for assigning value to the service rendered to highway traffic are needed. Valuable contributions have been made in this field, but it can not fairly be said that there now exists any uniformly recognized standard by which to determine whether the value of a proposed highway improvement will exceed the value of the unimproved road that it may replace by enough to justify the cost of its creation.

The objective is the development of a basis for the rational statement of economic values which will enable responsible engineers to obtain estimates of service value that are of the same order of merit as the estimates of cost now so commonly used.

Prof. A. H. Blanchard of the University of Michigan spoke on the topic, "Comprehensive research program justified because of increase in efficiency in highway improvement and economic utilization of highway transport." Professor Blanchard showed that various economies in design and in the selection of materials result from research but that one of the greatest savings accrues to highway transport which is benefited both by reduced cost of operation and by increased comfort and convenience.

#### REPORT OF COMMITTEE ON CHARACTER AND USE OF ROAD MATERIALS

H. S. Mattimore, of the Pennsylvania State Highway Department, chairman of the committee on character and use of road materials, reported that the committee's investigations indicate that the durability of concrete is affected by the durability of its constituent aggregates. It also appears that the nature of the aggregates may be the principal factor in expansion failures in concrete road slabs and bases. Other items of importance mentioned in the report are that the Jones-Talbot rattler test does not appear to be a reliable test for wear; that proportioning of concrete aggregates by weight seems to have merit; and that accelerated tests of aggregate for soundness are advisable.

As a part of the discussion of this report, W. E. Hawkins, maintenance engineer for the North Carolina State Highway Commission, presented a paper on "The economic selection of road building materials." Mr. Hawkins drew attention to the fact that most States possess large supplies of materials which do not meet the generally accepted standards, and so can not be appropriately used under standard specifications. Under such conditions it is the duty of engineers to make careful studies not only of the available materials themselves but of the results of unusual proportions and methods to ascertain whether practices can be devised which will justify their use. Such a program involves the use of laboratory facilities constructively, that is, for the determination of whether to use and how properly to use available materials, which represents an advance over the older practice of using laboratory facilities for the determination of whether materials of construction comply with pre-established standards.

#### REPORT OF THE COMMITTEE ON MAINTENANCE

The report of the committee on maintenance, W. H. Root, of the Iowa Highway Commission, chairman, called attention to the importance of snow removal, and added that more attention is required on the side of economy. Figures collected indicate that plows should be pushed rather than pulled; that ordinary push plows do not perform satisfactorily where the snow is over 24 inches deep and that improved V-type plows and rotary plows are to be had and should be used where heavier snowfalls are to be expected. A great deal of work can be saved by the erection of snow fences.

In the field of maintenance accounting it was recommended that highway officials adopt a standardized distribution of expenditures. Three headings were suggested, as follows: (1) Maintenance administration; (2) maintenance proper; and (3) betterments.

In his discussion of the committee's report, under the topic "The necessity of research to reduce the cost of highway maintenance," W. H. Connell, deputy secretary of highways and engineering executive, Pennsylvania State Highway Department, emphasized the need of more effective organization and of the application of standards of output and of cost per unit of output in developing real efficiency in maintenance. He also laid emphasis on the need of more complete recognition of the fact that restorations and replacements are strictly maintenance operations.

C. A. Hogentogler, of the Highway Research Board, read an interesting statement on the plans for a fact-finding survey on the economic value of reinforcing in concrete roads, which is being conducted by the board. In this study an effort is being made to determine from a survey of existing roads, the influence of steel reinforcement as affected by traffic, subgrade and climatic conditions, the conditions under which reinforcement is especially beneficial, the effect of slab design on the efficiency of reinforcement, and the relative cost of plain and reinforced concrete roads considering the initial investment, annual maintenance, and renewal charges.

The executive committee selected for the ensuing year is as follows: A. N. Johnson, chairman; W. H. Connell, vice chairman; Charles M. Upham, director; T. R. Agg, A. J. Brosseau, H. C. Dickinson, Thomas H. MacDonald, William Spraragen.

A complete report of the proceedings of the fourth annual meeting of the Highway Research Board may be secured by addressing Charles M. Upham, director, Highway Research Board, National Research Council, 2101 B Street NW., Washington, D. C.

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(Continued from page 4)

#### THE USEFULNESS OF THE RELATION

By application of this established relation, it is possible to make observations on the penetrations and corresponding loads of a small test area and to interpret results therefrom in terms of the supporting power that can be expected from a larger area. If a supporting mass of subgrade can be accurately reproduced in the laboratory and an accelerated supporting value test can be performed upon it with a small area, then its supporting value in the field under proposed or existent superimposed areas can be predicted or determined. This relation should also be valuable in predicting the penetrations of large areas when the penetration of a test area is known.

In connection with the results of this investigation, attention is called to the conclusion drawn by A. Bijls, chief of highways and bridges, of Belgium. An extract from his article on results obtained from an investigation which he conducted follows:

#### THE INFLUENCE OF THE SIZE OF SURCHARGED AREA [2]

The great influence of the size of surcharged area should be considered as one of the most important results of these experiments. When the area increases the elastic compression increases but $E_o$ decreases.

One might ask why this has not been established before. It is necessary to find the cause in the fact that, undoubtedly there never has been an attempt made to separate systematically the elastic compression from the permanent compression.

There probably exists a sufficiently definable relation between supporting power and permanent deformation; this force is probably independent of the elastic deformation.

For the permanent deformations, we may refer to the permanent slipping of soil particles. This necessitates a shift of equilibrium within the supporting mass of the soil; also, the increase of permanent deformation will constitute, in general, a certain indication that we are approaching the limit of the supporting power.

Since the mass, under a surcharged area, is seldom found largely in a definite state of equilibrium, it is in general impossible to establish the condition under which it exists in the field. We can not therefore make absolute theoretical deductions and one must have recourse to more fundamental hypotheses.

We can therefore assume that the permanent compressions are produced by displacements of sand grains and that elastic compressions are the result of elastic deformations or slipping, and in turn, that the pressure is transmitted under an angle of 45°.

Upon these hypotheses, the author arrives at the conclusion that the elastic compression of a surcharged area is proportional to the side of the area or to the square root of $A$, if the area is not square. The experiments seem to confirm this result.

[2] Extract from article in "Le Genie Civil" of May 26, 1923, by A. Bijls, chief, highways and bridges of Belgium.

# RECENT CONCLUSIONS IN HIGHWAY RESEARCH

By A. T. GOLDBECK, Chief, Division of Tests, U. S. Bureau of Public Roads

TO one in a position to survey the whole of the wide field of highway research and appreciate the relations of the various efforts made by numerous agencies one to another, there has come within the last year a very pronounced sense of a gradual convergence of the facts brought out by these efforts toward a well defined and rational process of highway design. Viewing the various single experiments separately one is apt to lose the sense of their position in the entire scheme and to miss the full appreciation of their value. It is therefore a good thing to stop for a moment occasionally and review the whole field, and obtain a new orientation to guide our further progress.

In attempting such a review at this time it may be well to consider not only the definite conclusions that have been reached, but also to include certain well defined indications which may later resolve themselves into conclusions. Through a knowledge of these indications it may be that much valuable time will be saved in the process of making the results of research a part of everyday practice.

### THE SUBGRADE

All highway engineers have observed the fact that the soils encountered in highway construction are variable in their behavior. They have observed that some of these soils shrink and crack when they become dry and swell upon taking up moisture; that some of them absorb large quantities of moisture by capillarity from below and are utterly incapable of carrying load when in a moist condition, while others, retaining uniformly low moisture content, are very stable, change only slightly in volume, and are affected little in their load-carrying ability. The characteristics of the various soils shade from one of these extremes to the other, and the question naturally arises as to what is the dividing line between good and bad soil characteristics from the highway engineer's standpoint and how should he take account of these variable characteristics of soils in highway design.

One of the first steps toward an answer to this question was to develop suitable tests in the laboratory for classifying soils according to characteristics which would be significant to the highway engineer; and we may now say definitely that we have succeeded in developing suitable tests for differentiating the various shades of quality in soils. The details of the tests developed have been described elsewhere. They include determinations of shrinkage, moisture equivalent, water absorbed by capillarity, slaking value, dye adsorption and bearing value, as well as the more familiar mechanical analysis.[1] A combination of some of these will serve to identify the essential characteristics of a subgrade material.

We have reached the stage where, for all practical purposes, we can conduct these tests in such a way that we can get identical results with identical samples. This is an important conclusion to the testing engineer but the highway engineer wants to know what test values are the significant ones, what values indicate bad soils and what values good soils. Research has advanced a long step in this direction but a true evaluation of the test results of subgrade samples must ultimately be arrived at through the coordination of a large number of laboratory tests with field behavior. Such coordination is a difficult task, for in addition to the influence of the subgrade in causing success or failure of a road surface, the coordinator must recognize and eliminate the influence of a large number of factors such as weight of traffic, condition of drainage, strength of materials, method of construction, and suitability of the design of the road surface for the traffic carried. By and large, however, it has been possible to make a step in the direction of coordinating laboratory test results with field behavior. Much credit is due to A. C. Rose, of the Bureau of Public Roads, District No. 1, Portland, Oreg., for his successful efforts toward this end. As a result of his work, the indications are very strong that when a soil has a so-called "moisture equivalent" in excess of 20 per cent or a lineal shrinkage value in excess of 5 per cent, it is apt to be unstable in that it will take up excessive amounts of moisture and consequently heave readily due to frost action or change excessively in volume due to moisture changes.

Under such conditions special precautions are necessary to insure against failure of the pavement due to subgrade movement. Thus, drainage, both surface and tile, might have to be provided to remove water in excess of capillary moisture. The pavement might, however, be strengthened by increasing the depth, by the use of steel or by the use of a layer of stable subgrade material. Sand or a similar cushion might be provided under the road surface or the soil might be treated to render it more stable by the use of admixtures.

Suitable field tests have been developed for determining the so-called "moisture equivalent" of the soil and this test combined with the shrinkage test, which might also be made in the field without elaborate equipment, gives an excellent idea as to whether or not subgrade trouble is to be expected. The ability to perform these two tests and to interpret them should be a part of every field engineer's equipment, and they should be used and the results noted, for they are highly significant.

### THE IMPROVEMENT OF BAD SUBGRADES

When a bad soil is encountered in road construction the question naturally arises as to what is the best thing to do with that soil or with the design of the road under construction. Years ago railroads both in this country and abroad discovered that in order to prevent the subsoil from working up through stone ballast it was necessary to provide a layer of finely granular material. In general, cinders have been used for this purpose but so also have bank-run gravel, ashes, and in one case it has been reported that cement was mixed with the soil. A bad soil primarily is one which has the ability to take up a large amount of water by capillarity, and which swells and shrinks excessively with changing moisture content, and which also has low bearing value in its moist condition. Such properties make it a poor supporting medium for highways and when the subgrade is to be improved it should be treated in such a way that: (1) It will have low shrinkage and expansion; (2) it will have high bearing value

[1] See PUBLIC ROADS, vol. 4, No. 3. p. 15.

at its highest moisture condition; (3) it will retain as little moisture as possible.

The sand-clay road furnishes an excellent example of the treatment of bad subgrades. Sticky, plastic clay is made into a stable nonyielding surface by the addition and admixture of sand. Cinders, or other fine granular material will accomplish the same end. These processes are so well developed that the following can be set down as an absolute conclusion:

> A poor subgrade material can be transformed into a good subgrade by the addition of sufficient fine granular material or by the use of a layer of suitable granular material.

#### EFFECT OF SIZE OF BEARING AREA ON BEARING VALUE

If the bearing value of the subgrade is important, the question immediately arises as to what effect the size of the bearing area has on the supporting value of the soil. The importance of the series of investigations described for the first time in this number of Public Roads is that it apparently provides the answer to this question. As the tests themselves are described on another page it will not be necessary to describe them in detail here, or to go into these conclusions except to repeat their most important conclusion, as follows:

> When like intensities of load are applied to bearing blocks of different size the relative penetrations of these areas into the soil will vary as the square roots of the areas.

This means that a large area will penetrate more than a small area when both are loaded with the same load per square foot. This will be an important conclusion to those interested in the design of footings for structures. It applies so long as the loads and the penetrations are relatively small thus enabling the soil to act largely elastically. Its application to large areas resting on a subgrade of unlimited depth has yet to be demonstrated.

#### BLANKET COURSES

In many States it is still the practice to build macadam on all kinds of subgrades in exactly the same manner as when this type of construction was introduced by John Louden McAdam. A layer of rather uniform coarse stone is laid directly on the subgrade in this type of construction. Under the action of the present-day heavy loads, and under the action of the roller, the subgrade materials, especially plastic clay materials, find their way up through the voids in the stone. The stone is thus lubricated with moist clay and the surfacing is thereby rendered much less capable of supporting loads because its effective depth is greatly decreased.

> It has been proven not particularly by theoretical tests but rather by actual construction in a number of different localities that a blanket course of fine granular material such as cinders, bank sand or gravel is very effective in preventing the clay subgrade from penetrating upward into macadam and its resistance to loads in this way is very greatly increased.

There is nothing new about this method. It has been practiced for years but its advantages seem not to have been universally recognized and it is well to emphasize them again at this time.

#### DRAINAGE

High moisture content in the subgrade is detrimental to road surfaces: (1) Because the bearing value of the subgrade is greatly decreased; (2) because the effect of freezing in causing unequal heaving of the road surface is more severe; and because (3), when the moisture dries from the subgrade, this drying is accompanied by considerable shrinkage of certain types of subgrades with a resulting nonuniform support for the road surface. The amount of harm which moisture can do is, of course, closely linked with the characteristics of the subgrade material. Moisture may be said to exist in the subgrade in the form of vaporized moisture, capillary moisture and free moisture. Free water is water which will drain out of the soil if a drainage system is provided, whereas the amount of capillary moisture is unaffected by any drainage system. When soils have an ability to take up large amounts of capillary water all types of drainage seem to be ineffective in preventing these soils from becoming very wet under the road surface and generally the water is supplied by capillarity at a higher rate than it can evaporate from beneath the surface. The investigations thus far made point very strongly to the following facts:

> Water exists in the subgrade: (*a*) As free water, (*b*) as capillary moisture; (*c*) as vaporized moisture.
>
> The moisture content of the subgrade is apt to increase under low temperature conditions due: (*a*) To the condensation of vaporized moisture, (*b*) to increase in capillary moisture.
>
> Drainage systems should be provided wherever free water is likely to exist but such systems are quite generally ineffective in removing any moisture in excess of free moisture.

#### EXPERIMENTS IN CONNECTION WITH ROAD DESIGN

A number of investigations have been made during the past year in connection with road design. They include both impact and static load tests on road slabs of different design laid at Arlington, Va., stress measurements in concrete roads, and special observations on a reinforced concrete road known as the Columbia Pike, near Arlington, Va.

The tests conducted at Arlington were made on 124 slabs of different design, some of them laid on a wet subgrade and some on a dry subgrade. They were tested in positions which are known to give the most severe stresses, namely, at the corner and along one of the edges. The tests were made first with an impact machine delivering blows, the range of which covered the range of blows known to be delivered by actual motor trucks. The conclusions thus far reached with regard to the different slabs are as follows:[2]

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

[2] Impact tests on concrete pavement slabs, by L. W. Teller, Public Roads, April, 1924, vol. 5, No. 2, p. 1.

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.

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.

The portions of slabs left unharmed have subsequently been tested under static load, both at the corners and along the edges with the following results:[3]

The static resistance of both the corners and the edges of rigid slabs is affected by the nature of the subgrade; the more resistant the subgrade to load, the greater the resistance of the slab and vice versa.

The resistance of rigid slabs to static loads does not vary with the square of the depth but as some power greater than one and less than two. About 1.75 is the average value, the exponent being higher for slabs on the wet subgrade and lower for those on the dry subgrade.

The corners and edges of concrete slabs of the size and thickness tested offer about the the same degree of resistance to static loads.

The presence of mesh reinforcement as employed in the slabs under consideration, does not increase the load-carrying capacity of concrete slabs but does give rise to a tendency to hold together and resist complete failure after initial or elastic failure has taken place.

Bituminous topping laid on rigid slabs does not increase the resistance of the slabs to static load.

At the ordinary summer temperatures encountered, bituminous slabs of the types tested show no slab strength. The load supporting value of such slabs is greatly influenced by the subgrade support.

## STRESS MEASUREMENTS IN CONCRETE PAVEMENTS

By the use of a graphic strain gauge developed by the Bureau of Public Roads a large number of measurements of fiber deformations have been made in concrete pavements of different design in order to determine the effect of traffic loads on the bending stresses produced in the slabs. The instrument has proved to be useful for determining both static and impact stresses and furnishes a means for determining whether or not concrete roads are overstressed.

The procedure in making these measurements has been to install a number of graphic strain gauges just beneath the surface of concrete pavements, placing the instrument in positions which will permit of determining longitudinal and transverse stress in important positions throughout the slab. Heavy trucks are then run over the pavement in different positions, first with the rear wheels along the outer edge, then several feet from the edge, and finally with the wheels trailing along the center joint, if any exists. The following conclusions are drawn from these tests:

In slabs of uniform thickness the highest longitudinal stresses exist along the edge and along the center joint. They occur with wheels running directly over the edge of the slab and along the center joint. The highest tension might occur either at the bottom or the top of the slab at the edge. High tension also occurs transversely at a transverse joint. The tension developed at intermediate positions is very much smaller. It is therefore most important that the edges of a slab be made of sufficient thickness so that the bending resistance along the edge will not be exceeded. This applies to all edges, whether they be along the side, at the center joint, or at a transverse joint.

If there is a center joint with no means for transferring load across the joint, the edge along the center joint is stressed to about the same amount as the outside edge of the pavement and should be of the same thickness. When an effective means is provided, however, for transferring load (such as tongue-and-groove construction), the stress along the center joint is considerably decreased.

High tension is produced in the top of the slab near a corner. This tension occurs with a heavy wheel load at the corner. It is, however, considerably less than the longitudinal tension along the bottom outside edge of the slab directly under a heavy wheel load.

A concrete slab should have a thickened edge in order to receive uniformly distributed maximum stress under traffic. This conclusion bears out the conclusions which have been reached as a result of the Pittsburgh Test Road and of the Bates Test Road.

When a center longitudinal joint is provided with an efficient means for transferring load across the joint, the thickness of the slab at the joint should be equal to not less than 0.7 of the thickness at the outside edge in order that like maximum stresses will be received in these two positions.

It is quite strongly indicated that any road roughness or truck conditions tending to produce impact will likewise greatly increase the fiber deformation and the possible likelihood of cracking on this account.

[3] Static load tests on pavement slabs, by J. T. Thompson, PUBLIC ROADS, November, 1924, vol. 5, No. 9, p. 1.

It is quite evident that maximum stresses under the edge of the slab are produced only with the truck wheel trailing along that edge, and that these stresses are very greatly reduced when the truck wheels trail along a line no more than 1 foot distant from the edge. This suggests that where curbs are used which prevent the traffic from reaching the extreme edges, thickened edges probably are not necessary.

#### INDICATIONS FROM COLUMBIA PIKE EXPERIMENTS

The Columbia Pike investigations have been described in the October, 1924, issue of Public Roads.[4] Briefly the road consisted of 32 sections of both plain and reinforced concrete. The variations in the sections consisted of changes in thickness, changes in cross-section design, the use of cinders under some of the sections and the use of various percentages of reinforcing steel.

Careful observations were made of the development of cracking in the sections and subgrade samples were taken from time to time to note the moisture content and also physical characteristics of materials under various sections of the road.

An analysis of the subgrade samples and of the physical condition of the pavement as revealed by the record of longitudinal cracking indicates that the subgrade has a decided influence on the condition of the pavement. Materials subject to high volumetric change and having high "moisture equivalents" generally produce the most extensive longitudinal cracking. The most striking observations from these tests, however, have to do with the behavior of the various sections as influenced by the amount of longitudinal reinforcing steel.

In sections which have from eight to fourteen ¾-inch round deformed rods placed lognitudinally, transverse cracks have occurred at frequent intervals a few feet apart. These cracks, however, are very fine. Sections which have eight ¾-inch rods have not cracked as frequently as those having fourteen ¾-inch rods. One section having four 1-inch rods has cracked slightly less than sections having eight ¾-inch rods. Sections which have reinforcing varying from four ¾-inch to four ½-inch rods are free from fine transverse cracks but have wide, open cracks similar to those found in plain concrete sections but spaced at greater distances—60 to 70 feet—as compared with 40 to 50 feet in plain concrete slabs. Sections which are reinforced with 25 and 50 pounds of mesh per 100 square feet have no fine cracks, but do have open cracks spaced at greater distances than would ordinarily be found in plain concrete. In order to discover the cause for the action of these several sections, the cracks were opened in a number of instances, thus exposing the steel.

It was found that in those sections having eight or more ¾-inch deformed round bars, no change in diameter of the bars had occurred. In the section reinforced with four 1-inch bars, slight reductions in diameter were found. In the section having four ¾-inch bars, the diameter was reduced to ⅝ inch. In the sections having eight ½-inch rods the diameter has been reduced to approximately ⅜ inch, while in still another section having only four ½-inch bars the bars had completely broken with a reduction in diameter to about ¼ inch. In sections reinforced with mesh to the extent of 25 and 50 pounds per 100 square feet, the mesh was completely broken at the cracks. The indications are very strong therefore:

(1) That longitudinal steel up to a certain amount does increase the spacing of transverse cracks and these cracks will open on contraction.

(2) That longitudinal steel above this amount might produce fine transverse cracks, spaced in some cases only a few feet apart.

#### TEST OF SKEW ARCHES

In the past there have been failures of skew arches generally through excessive stress at the obtuse angle end of the abutment and there are a number of instances of skew arches now constructed which are showing signs of distress at this location. Bridge engineers are in a quandary as to just what constitutes a proper basis for the design of arches in which the abutments are inclined at an angle with the axis of the roadway. A series of tests which is still under way at the Bureau of Public Roads is showing some very striking indications of the wide variation in abutment reactions, both horizontal and vertical, depending upon the angle of skew. Thus far arches have been tested with 60°, 45°, and 30° angles of skew and a 15° arch is now under load. The arches are 7 feet in span, measured on the center line of the roadway, the ring is 4½ feet wide at right angles to the center line of the roadway and the rise is one-fifth of the span.

The principal object sought is the determination of the distribution of abutment reactions, both horizontal and vertical, from one end of the abutment to the other. The results obtained on the three arches tested are very clear in showing that by far the greater amount of the load is transmitted to the obtuse angle end of the abutment. In the case of the 60° skew both the vertical and horizontal reactions at the acute angle end are practically zero and there is a straight-line distribution of vertical reaction from the acute angle to the obtuse angle end in all three arches. The more nearly the angle of the arch approaches a right angle, the more nearly uniform does the distribution of both vertical and horizontal reactions become. It would be premature to draw definite conclusions from these tests at the present time but the indications are quite strong that for arches of these proportions the centroid of the vertical and horizontal reactions for a 60° skew is located one-third of the length of the abutment measured from the obtuse angle, and that its location shifts between that point and the center as the angle of skew decreases. The above is a rather rough statement of the indications but a more detailed statement will be forthcoming shortly in a technical paper covering these investigations.

#### IMPACT EXPERIMENTS ON BRIDGES

Cooperative impact tests are now being conducted jointly between the Bureau of Public Roads and Iowa State College.[5] Thus far the principal conclusion to be reached is that:

[4] Reinforcing and the subgrade as factors in the design of concrete pavements, by J. T. Pauls, Public Roads, October 1924, vol. 5, No. 8, p. 1.

[5] Impact tests on highway bridges, Public Roads, September, 1924, vol. 5, No. 7,

> The accurate determination of impact stresses is now possible with the use of several different types of instruments. It is also possible to measure the force of the blow delivered by motor trucks as influenced by a number of factors, such as bridge floor roughness, deflection, cushioning, etc.

A number of impact stresses have been measured but definite conclusions are hardly forthcoming at the present time.

###### EARTH PRESSURES ON BRIDGE ABUTMENTS OR RETAINING WALLS

The various State highway departments make a wide range of assumptions with regard to earth pressures existing behind retaining walls. A very interesting series of tests has recently been completed in which soil pressure measuring cells have been embedded back of retaining walls during their construction and later, after the fill has been completed measurements of pressure have been obtained. These measurements are quite illuminating and they surely point to the necessity for recognizing the existence of higher earth pressures than are generally thought to exist. One series of tests includes the measurement of pressures back of a bridge abutment some 25 feet in height. The adjacent stream rises to a considerable height during the spring of the year and the filling material becomes thoroughly saturated and slowly dries out during the summer. The pressure readings in this particular case show conclusively that the pressures increase and decrease in accordance with the percentage of moisture in the filling material which in this case was a clay-loam soil. The pressure varies from that which would be caused by a fluid weighing 44.1 pounds per cubic foot to that due to a fluid weighing 29.8 pounds per cubic foot. It is interesting to note that Rankin's formula for pressure under the assumption of earth weighing 100 pounds per cubic foot with an angle of repose of 1½ to 1 gives a pressure equivalent to that of a fluid weighing 28.7 pounds per cubic foot.

Other tests made on bridge abutments in Washington, D. C., show correspondingly high pressures and the pressure varies with the manner of filling. It is indicated very strongly:

> That provision for draining the fill should be one of the major features of the work which should be carefully designed and executed in the construction of the wall or abutment and that the earth pressure should not be taken at less than that which would be developed by a fluid weighing 28 to 30 pounds per cubic foot.

###### INVESTIGATIONS DEALING WITH MATERIALS OF CONSTRUCTION

Among the outstanding investigations made during the past year, from the standpoint of its possible economic importance, is the study of the bulking effect of moisture in sand.

Concrete is ordinarily proportioned with the thought that the proportions used will give a certain minimum desired strength and certain desired qualities of workability and density. The general ideas which engineers now have with regard to the strength of concrete are based largely on laboratory tests in which the sand is invariably measured in an air-dry condition. In the field the sand is generally moist and is therefore bulked depending upon its moisture and fineness up to 25 per cent of its air-dry volume. There is little wonder then, that concrete proportioned by volume with moist sand does not have the same characteristics as concrete proportioned in the manner ordinarily used in the laboratory nor need there be much surprise that field-proportioned concrete, in general, is harsher and does not possess the workability of concrete of the same nominal proportions as made in the laboratory, and, further, it is quite plain why the yield of field concrete is sometimes less than is anticipated.

The bulking tests made during the past year at least point to the desirability of basing the proportions of concrete on the volume of sand as measured in its dry condition. The proportions would then have a much more definite meaning than they have at present, the sand now being measured without regard to its moisture content and condition of bulking. More study should be given to this subject. It has considerable significance. It is interesting to note that proportioning by weight as now practiced in Iowa very largely eliminates the difficulty due to the bulking of sand, but other methods also may be employed.

###### INVESTIGATIONS OF THE CHARACTERISTICS OF AGGREGATES SUITABLE FOR CONCRETE PAVEMENTS

One rather extensive investigation, completed during the past year at Arlington, Va., was made primarily for determining the limit of characteristics of aggregates suitable for use in concrete pavement construction. The main question involved was the determination of the minimum standard of quality. To answer this question a number of aggregates were imported from different sections of the country and a concrete-surfaced circular track was constructed with these materials. This track was tested by a special-wear machine, first fitted with rubber tires alone then equipped with tire chains.

The conclusions which have been drawn as a result of these tests are based on three premises: [6]

1. That on the average 18-foot concrete road, approximately 10 per cent of the total traffic moving in both directions passes over a band 6 inches in width at the point of maximum concentration. Therefore, the traffic passing over the test road should be multiplied by at least 10 to obtain the equivalent volume of traffic on an actual pavement.

2. That the comparative resistance of each test section to the surface wear produced by the tire chains is an indication of the comparative resistance which would be offered by the concrete to wear or disintegration at the edges of exposed joints and cracks under service conditions.

3. That conditions which cause surface wear, such as steel tires, tire chains tracking through snow, etc., are present to such an extent as to make it necessary to give the question of wear consideration in the selection of concrete aggregates.

From the results obtained the following conclusions were drawn:

> That the rate of wear of stone concrete is, in general, not affected by the coarse aggregate, provided the coarse aggregate is equal or superior to the mortar matrix in resistance to wear.

[6] Wear of concrete pavement tested, by F. H. Jackson and J. T. Pauls, PUBLIC ROADS, May, 1924, vol. 5, No. 3, p. 1.

That excessive wear will result from the use of very soft stone as coarse aggregate even though used in conjuction with a mortar of satisfactory quality. From the results of these comparative tests, it would appear that stone with a percentage of wear over seven should not be used in concrete road construction.

That gravel concrete, in general, is at least as satisfactory from the standpoint of wear as stone concrete.

That gravels consisting essentially of siliceous materials are superior as regards both the amount and uniformity of wear to those containing a preponderance of calcareous fragments.

That gravels consisting of rounded particles are as satisfactory from the standpoint of wear as those consisting either wholly or in part of angular or crushed fragments.

That small amounts of shale occurring in the coarse aggregate will cause both excessive and uneven wear.

That the modified abrasion test for gravel in its present form is not an indication of the wear-resisting properties of coarse aggregates. It is suggested that if the severe impact action of the steel balls were decreased, much more indicative results would be secured.

The blast furnace slags should prove satisfactory for use in concrete pavements provided the proportion of light, porous slag is so controlled that the weight per cubic foot will be at least 70 pounds.

That the presence of large amounts of light, porous fragments in blast furnace slag will cause excessive wear.

That somewhat better results are secured by the use of the smaller sizes of slag.

That slag or stone screenings are, in general, unsatisfactory as substitutes for natural sand as fine aggregate in concrete road construction.

That the copper and lead smelter slags used in these tests would make satisfactory aggregates for concrete road construction from the standpoint of wear.

That coarse sands, other things being equal, show greater resistance to wear than fine sands.

That the so-called "tensile-strength-ratio" test is no indication of the wear-resisting properties of concrete made with these sands.

That the Talbot-Jones wear test is not, in general, an indication of the wear which takes place under traffic.

That neither the crushing nor the transverse strength of concrete is a measure of its wear-resisting properties.

That the addition of hydrated lime in the proportion used in these tests does not affect the wear-resisting properties of concrete.

That so far as resistance to wear alone is concerned, increasing the cement content beyond a cement-sand ratio of 1:2 does not materially affect the concrete. Leaner mixes on the other hand show marked increase in wear.

That unusual precautions should be taken in using mine chats or other similar harsh-working materials, so as to increase workability to a maximum and thus make possible a smoother surface finish.

That, other things being equal, either an excessively dry or an excessively wet mix will show less resistance to wear than concrete of medium consistency.

A number of other tests are under way covering a wide variety of subjects having to do with both materials and design. From these researches indications and definite conclusions are gradually being drawn. All of these investigations should be of interest to the highway engineer. They involve such tests as fatigue of concrete, the effect of calcium chloride curing on concrete, investigations of bituminous materials, the study of the laws governing the stability of bituminous mixtures, causes of scaling of concrete roads, and a large number of other problems, each having an important bearing on the production of better and more economical pavements and structures.

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## COMPARISONS OF THE STRENGTH OF CONCRETE IN TENSION AND COMPRESSION

By **N. M. FINKBINER**, Engineer of Materials, Oregon State Highway Commission

During the 1922 construction season, the materials department of the Oregon State Highway Commission decided to run a few tension tests on concrete, to see if a general relation exists between the tensile and compressive stength. Some of the specimens were cast in the laboratory using a variety of materials, and some were cast in the field on the various concrete paving jobs then under construction. The laboratory specimens, both tension and compression, were cured in moist sand. In the field both classes of specimens were cured on top of the pavement, receiving the same conditions of curing as the pavement itself, which is standard Oregon practice.

The forms in which the tension specimens were cast, were shaped like a standard cement briquette, but were 36 square inches in cross section at the narrow part, the dimensions being 6 by 6 inches. The compression specimens were cast in the regular 6 by 12 inch sheet metal molds. Jaws which proved very satisfactory were designed to be used on a universal testing machine.

The specimens cast in the field gave as an average 288 pounds to the square inch in tension, and 3,185 pounds to the square inch compression. This indicates that the compression is about 11.06 times the tension. The specimens cast in the laboratory gave the compression as 8.9 times the tension. These averaged 241 pounds to the square inch tension, and 2,160 pounds to the square inch compression. The laboratory concrete specimens were expected to show a discrepancy, should any exist, on account of the fact that while the mixes were all 1:2:3, and the consistencies were kept as closely as practicable the same, different mineral aggregates were used, some of which would not pass specifications, nor be permitted to be used in State work. Under general field conditions in Oregon, therefore, the compression in pounds per square inch divided by 10 will give approximately the strength of the concrete in tension at the age of 28 days.

# HIGHWAY INCOME FROM THE MOTOR VEHICLE

By HENRY R. TRUMBOWER, Economist, United States Bureau of Public Roads

COMPARING the two principal means of transportation in the United States, namely the railroads and highways, certain similarities and differences are noted. The railroad transportation system of the country is wholly in private hands. The roadbed and tracks and also the equipment are owned by organizations of private investors. With respect to highway transportation, on the other hand, we find the situation quite different. The equipment, i. e., the motor vehicles, both passenger automobiles and motor trucks, the storage houses and everything that pertains to the operation of the cars and trucks is owned by individuals or by private organizations. The roadbed itself is owned, constructed, and maintained by the public, except in a very few instances where toll roads and toll bridges still exist. In railroad transportation the rate which one pays for transporting passengers or freight is intended to cover the costs relating to the operation of the equipment and the maintenance of the roadbed and track and also the interest on the value of the property used. In highway transportation we find that the same costs are present which prevail with reference to railroad transportation. The cost of the automobile or the motor truck and its operating costs have to be met, and the cost of constructing and maintaining the highway has to be paid by some one. Under the system which prevails at the present time the operator and owner of the motor vehicle bears its operating costs and the public, through State highway commissions or through local highway organizations, bears the costs of constructing and maintaining the highway. One of the main problems of highway finance is to apportion this highway cost among those who, on the one hand, make a direct use of the highway and benefit thereby, and those, on the other hand, who are benefited indirectly through the development of the highway system. Leaving out of consideration the toll roads, which formerly were fairly numerous, but now have been largely taken over by the public, the public pays for the construction and maintenance of the highways. Formerly the funds necessary for this purpose were raised by general property taxes or, in some cases, from assessments levied on land directly adjacent to or close to the improved highway. To these sources of income there has been added since the advent of the motor vehicle and the growth of a demand by the owners of such vehicles for more extensive highway improvement, another source, which is the tax laid upon the owners of the vehicles, or, in other words, the road users.

These motor-vehicle revenues are raised mainly by two methods: First, by the licensing of the motor vehicles and the exaction of a special fee in connection therewith; and, second, by the taxation of gasoline, which provides revenues proportionate to the use made

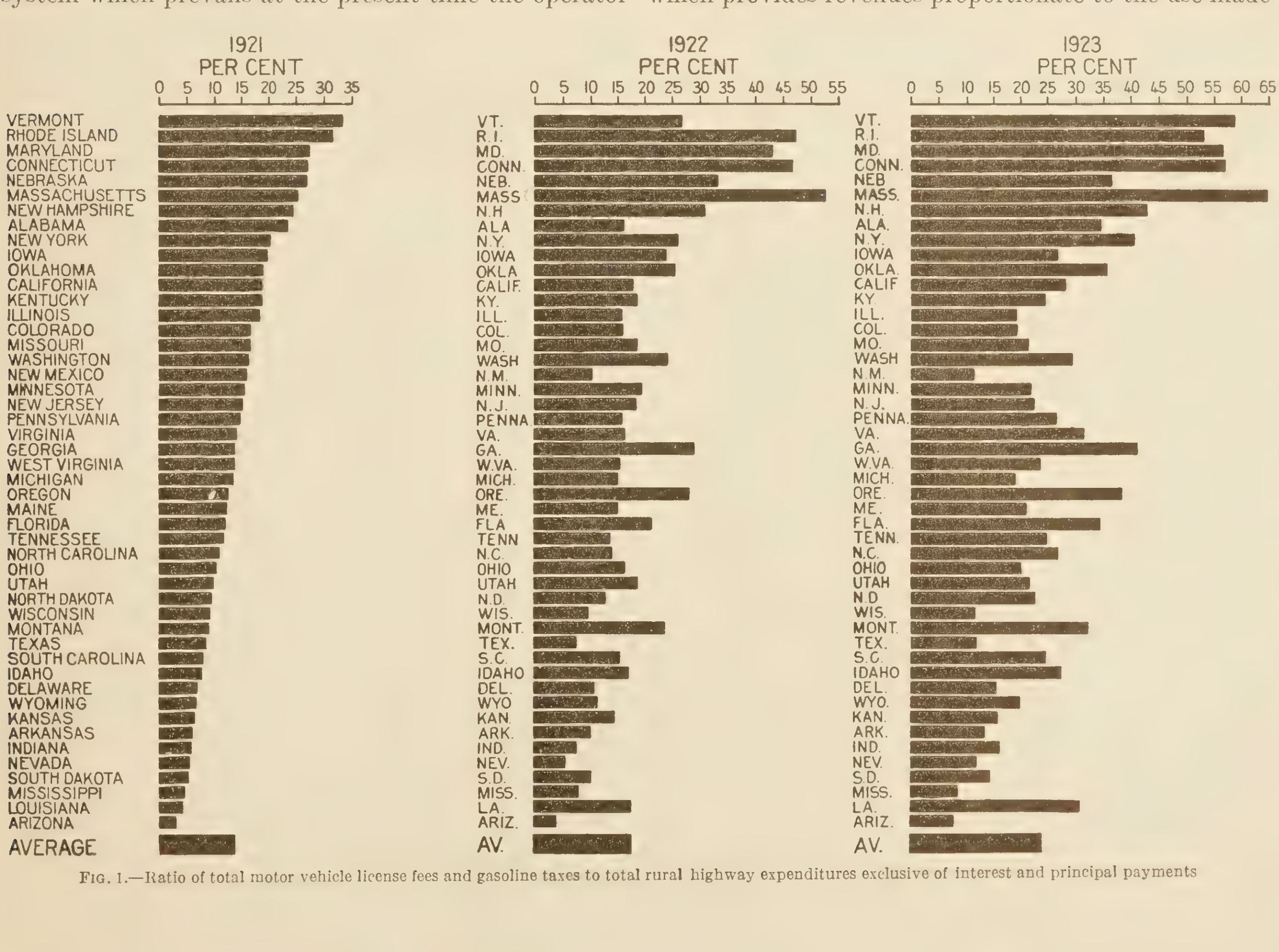


FIG. 1.—Ratio of total motor vehicle license fees and gasoline taxes to total rural highway expenditures exclusive of interest and principal payments

of the streets and roads. Through the use of these two methods the automobile is called upon to bear directly a part of the total cost of highway construction and maintenance.

### MOTOR VEHICLE REVENUES COMPARED WITH TOTAL HIGHWAY EXPENDITURES

In Tables 1, 2, and 3 and Figure 1 are shown by States for the years 1921, 1922, and 1923, respectively, the total highway expenditures and the total revenues derived from motor-vehicle license fees and from the gasoline taxes and also the ratios which these total motor vehicle revenues bore to the total highway expenditures. The expenditures as tabulated here for the year 1921 cover the items of construction and maintenance of roads and bridges, administration and engineering, and the purchase and repair of machinery and equipment and general and miscellaneous expenses. Payments made as interest and principal payments on highway bonds are excluded. For 1922 the total construction and maintenance items were obtained directly from State reports, and the items of purchase and repair of equipment and general and miscellaneous expense were estimated as bearing the same ratio to the construction and maintenance items as in the previous year. For 1923 no definite expenditure figures for the individual States are available. However, it is known that the expenditures made by the State highway departments during the year were practically the same as in 1922, and there is strong indication that the total 1923 expenditures were practically the same as the 1922 expenditures for the country as a whole, although there may have been variations for individual States which these estimates do not take into account. The percentages show at least the trend of the ratio between motor-vehicle revenues and highway expenditures. In Figure 1 the ratios which the motor-vehicle revenues bear to the total highway expenditures for these three years are compared, the States being arranged in the order of the 1921 ratios.

In 1921 the total highway expenditures of the country, exclusive of interest and principal payments, amounted to $947,306,826, and the total license fees and gasoline taxes, exclusive of the District of Columbia, were $127,571,331, which was 13.4 per cent of the total highway expenditures. The total highway expenditures for 1922 were $931,886,835; and in that year the total motor vehicle-revenues amounted to $160,854,384, or 17.2 per cent of the highway expenditures. Using the same expenditure figures for 1923 as for 1922, we find that the total motor-

TABLE 1.—*Total highway expenditures and motor vehicle revenues, 1921*

| State | Total highway expenditures, less interest and principal payments | Total license fees and gasoline taxes | |
|---|---|---|---|
| | | Amount | Percentage of total highway expenditures |
| | | | *Per cent* |
| Alabama | $4, 881, 701 | $1, 147, 265 | 23. 5 |
| Arizona | 9, 804, 812 | 283, 898 | 2. 9 |
| Arkansas | 19, 353, 806 | 1, 026, 544 | 5. 8 |
| California | 36, 614, 695 | 6, 834, 090 | 18. 7 |
| Colorado | 8, 903, 278 | 1, 465, 532 | 16. 5 |
| Connecticut | 8, 445, 716 | 2, 306, 350 | 27. 2 |
| Delaware | 5, 570, 049 | 375, 469 | 6. 7 |
| Florida | 8, 541, 667 | 1, 018, 712 | 11. 8 |
| Georgia | 14, 571, 511 | 2, 008, 099 | 13. 7 |
| Idaho | 10, 786, 437 | 841, 213 | 7. 8 |
| Illinois | 37, 639, 731 | 6, 803, 556 | 18. 1 |
| Indiana | 44, 142, 148 | 2, 422, 227 | 5. 5 |
| Iowa | 39, 324, 553 | 7, 719, 128 | 19. 6 |
| Kansas | 22, 054, 780 | 1, 400, 000 | 6. 4 |
| Kentucky | 11, 683, 078 | 2, 183, 826 | 18. 7 |
| Louisiana | 11, 838, 160 | 453, 276 | 3. 8 |
| Maine | 8, 259, 725 | 1, 004, 750 | 12. 1 |
| Maryland | 8, 968, 584 | 2, 460, 162 | 27. 4 |
| Massachusetts | 18, 634, 337 | 4, 717, 389 | 25. 3 |
| Michigan | 50, 708, 494 | 6, 751, 925 | 13. 3 |
| Minnesota | 37, 144, 902 | 5, 672, 424 | 15. 3 |
| Mississippi | 17, 256, 456 | 751, 946 | 4. 3 |
| Missouri | 15, 240, 889 | 2, 505, 354 | 16. 4 |
| Montana | 9, 276, 916 | 823, 320 | 8. 9 |
| Nebraska | 10, 361, 131 | 2, 824, 811 | 27. 0 |
| Nevada | 1, 971, 895 | 102, 800 | 5. 2 |
| New Hampshire | 3, 598, 921 | 876, 322 | 24. 4 |
| New Jersey | 26, 334, 950 | 3, 974, 064 | 15. 0 |
| New Meixco | 3, 369, 464 | 531, 921 | 15. 8 |
| New York | 50, 913, 742 | 10, 288, 858 | 20. 2 |
| North Carolina | 25, 617, 735 | 2, 765, 258 | 10. 8 |
| North Dakota | 7, 247, 231 | 683, 053 | 9. 5 |
| Ohio | 65, 777, 680 | 6, 894, 160 | 10. 2 |
| Oklahoma | 13, 931, 478 | 2, 619, 714 | 18. 8 |
| Oregon | 26, 476, 121 | 3, 270, 058 | 12. 4 |
| Pennsylvania | 69, 580, 813 | 10, 305, 499 | 14. 8 |
| Rhode Island | 2, 693, 534 | 848, 724 | 31. 5 |
| South Carolina | 9, 444, 868 | 741, 115 | 7. 9 |
| South Dakota | 13, 752, 165 | 720, 587 | 5. 2 |
| Tennessee | 12, 046, 793 | 1, 387, 870 | 11. 5 |
| Texas | 45, 715, 452 | 3, 806, 395 | 8. 3 |
| Utah | 4, 564, 239 | 441, 360 | 9. 7 |
| Vermont | 2, 150, 484 | 668, 289 | 33. 1 |
| Virginia | 14, 383, 422 | 2, 021, 146 | 14. 0 |
| Washington | 22, 229, 050 | 3, 612, 578 | 16. 2 |
| West Virginia | 9, 110, 841 | 1, 250, 526 | 13. 7 |
| Wisconsin | 40, 774, 180 | 3, 671, 646 | 9. 0 |
| Wyoming | 4, 329, 212 | 288, 122 | 6. 6 |
| | 947, 306, 826 | 127, 571, 331 | 13. 4 |

TABLE 2.—*Total highway expenditures and motor-vehicle revenues, 1922*

| State | Total highway expenditures, less interest and principal payments | Total license fees, and gasoline taxes | |
|---|---|---|---|
| | | Amount | Percentage of total highway expenditures |
| | | | *Pe rcent* |
| Alabama | $7, 771, 268 | $1, 262, 800 | 16. 2 |
| Arizona | 9, 562, 166 | 374, 468 | 3. 9 |
| Arkansas | 12, 292, 781 | 1, 238, 271 | 10. 0 |
| California | 46, 886, 633 | 8, 384, 606 | 17. 9 |
| Colorado | 10, 334, 618 | 1, 636, 542 | 15. 9 |
| Connecticut | 9, 118, 682 | 4, 256, 991 | 46. 6 |
| Delaware | 3, 944, 090 | 426, 377 | 10. 8 |
| Florida | 10, 549, 971 | 2, 231, 563 | 21. 2 |
| Georgia | 8, 878, 320 | 2, 569, 235 | 29. 0 |
| Idaho | 4, 784, 041 | 812, 943 | 17. 0 |
| Illinois | 50, 496, 350 | 7, 882, 482 | 15. 6 |
| Indiana | 40, 689, 112 | 2, 999, 588 | 7. 4 |
| Iowa | 33, 401, 849 | 7, 923, 388 | 23. 7 |
| Kansas | 21, 709, 498 | 3, 100, 000 | 14. 3 |
| Kentucky | 13, 884, 050 | 2, 587, 993 | 18. 6 |
| Louisiana | 12, 786, 192 | 2, 240, 618 | 17. 5 |
| Maine | 9, 467, 482 | 1, 417, 507 | 15. 0 |
| Maryland | 7, 497, 713 | 3, 220, 387 | 43. 0 |
| Massachusetts | 10, 843, 800 | 5, 685, 527 | 52. 6 |
| Michigan | 55, 516, 403 | 8, 305, 022 | 15. 0 |
| Minnesota | 33, 644, 891 | 6, 543, 685 | 19. 5 |
| Mississippi | 18, 078, 341 | 1, 444, 542 | 8. 0 |
| Missouri | 18, 913, 961 | 3, 512, 182 | 18. 6 |
| Montana | 3, 635, 170 | 863, 811 | 23. 7 |
| Nebraska | 9, 134, 304 | 3, 031, 699 | 33. 2 |
| Nevada | 2, 240, 623 | 120, 937 | 5. 4 |
| New Hampshire | 4, 047, 980 | 1, 246, 098 | 30. 9 |
| New Jersey | 34, 195, 623 | 6, 251, 418 | 18. 3 |
| New Mexico | 4, 159, 433 | 426, 901 | 10. 2 |
| New York | 48, 952, 729 | 12, 736, 364 | 26. 0 |
| North Carolina | 24, 949, 161 | 3, 493, 827 | 14. 0 |
| North Dakota | 5, 417, 705 | 698, 931 | 12. 9 |
| Ohio | 48, 234, 644 | 7, 888, 992 | 16. 3 |
| Oklahoma | 10, 721, 964 | 2, 729, 169 | 25. 5 |
| Oregon | 15, 851, 436 | 4, 440, 779 | 28. 0 |
| Pennsylvania | 80, 699, 582 | 12, 575, 380 | 15. 6 |
| Rhode Island | 2, 414, 704 | 1, 139, 742 | 47. 2 |
| South Carolina | 9, 810, 758 | 1, 501, 888 | 15. 3 |
| South Dakota | 12, 116, 778 | 1, 232, 232 | 10. 2 |
| Tennessee | 11, 659, 311 | 1, 592, 230 | 13. 7 |
| Texas | 56, 022, 344 | 4, 261, 488 | 7. 6 |
| Utah | 3, 909, 295 | 729, 455 | 18. 7 |
| Vermont | 2, 882, 200 | 781, 982 | 27. 0 |
| Virginia | 15, 143, 391 | 2, 467, 346 | 16. 2 |
| Washington | 17, 564, 039 | 4, 245, 500 | 24. 1 |
| West Virginia | 12, 546, 208 | 1, 936, 079 | 15. 4 |
| Wisconsin | 41, 706, 869 | 4, 088, 570 | 9. 8 |
| Wyoming | 2, 818, 372 | 316, 849 | 11. 2 |
| | 931, 886, 835 | 160, 854, 384 | 17. 2 |

vehicle revenues of $225,427,013, again exclusive of the District of Columbia, amounted to 24.2 per cent of the amount of money spent for highway construction and maintenance. In 1924 it is believed that the total motor-vehicle revenues from license fees and gasoline taxes will approximate $300,000,000, which will be about one-third of the total highway expenditures assuming that the 1924 expenditures will not be greatly different from those of preceding years.

During this four-year period the increase in motor-vehicle revenues was about 135 per cent of the 1921 amount, while the motor-vehicle registration increased but 50 per cent. The increase in revenues was due not only to the larger number of cars registered but also to the raising of the license fees on passenger cars and the further increased fees on motor trucks and to the added revenues produced by the gasoline tax.

In 1923 there were five States—Massachusetts, Vermont, Connecticut, Maryland, and Rhode Island—in which the motor-vehicle revenues were more than 50 per cent of the total highway expenditures for the year. In Massachusetts they amounted to 64.5 per cent, and this State was the only one in which the ratio was over 70 per cent in 1922. The five States which raised the smallest part of the total funds expended by motor-vehicle taxation in 1923 were Arizona, Mississippi, New Mexico, Texas, and Wisconsin, in which States the ratio between motor-vehicle revenues and highway expenditures was less than 12 per cent. It will be observed also that in 1923 there were 26 States in which motor-vehicle revenues were less than 25 per cent of the total highway expenditures and 22 in which they were greater, whereas in 1921 there were only six States—Connecticut, Maryland, Massachusetts, Nebraska, Rhode Island, and Vermont—in which the motor-vehicle revenues equaled or exceeded 25 per cent of the highway expenditures. The trend during the three-year period will be clear from these comparisons.

TABLE 3.—*Estimated total highway expenditures and motor-vehicle revenues, 1923*

| State | Total highway expenditures, less interest and principal payments | Total license fees and gasoline taxes: Amount | Total license fees and gasoline taxes: Percentage of total highway expenditures |
|---|---|---|---|
| | | | *Per cent* |
| Alabama | $7,771,268 | $2,674,103 | 34.4 |
| Arizona | 9,562,166 | 755,794 | 7.9 |
| Arkansas | 12,292,781 | 1,654,289 | 13.5 |
| California | 46,886,633 | 13,127,437 | 28.0 |
| Colorado | 10,334,618 | 1,972,572 | 19.1 |
| Connecticut | 9,118,682 | 5,209,655 | 57.0 |
| Delaware | 3,944,090 | 604,788 | 15.3 |
| Florida | 10,549,971 | 3,604,108 | 34.1 |
| Georgia | 8,878,320 | 3,658,910 | 41.2 |
| Idaho | 4,784,041 | 1,310,502 | 27.4 |
| Illinois | 50,496,350 | 9,653,796 | 19.1 |
| Indiana | 40,689,112 | 6,600,143 | 16.2 |
| Iowa | 33,401,849 | 8,827,063 | 26.5 |
| Kansas | 21,709,498 | 3,435,606 | 15.8 |
| Kentucky | 13,884,050 | 3,359,168 | 24.2 |
| Louisiana | 12,786,192 | 3,945,679 | 30.9 |
| Maine | 9,467,482 | 1,946,345 | 20.8 |
| Maryland | 7,497,713 | 4,225,259 | 56.2 |
| Massachusetts | 10,843,800 | 6,989,633 | 64.5 |
| Michigan | 55,516,403 | 10,500,786 | 18.9 |
| Minnesota | 33,644,891 | 7,316,772 | 21.8 |
| Mississippi | 18,078,341 | 1,545,472 | 8.5 |
| Missouri | 18,913,961 | 4,016,384 | 21.2 |
| Montana | 3,635,170 | 1,170,871 | 32.2 |
| Nebraska | 9,134,304 | 3,353,175 | 36.6 |
| Nevada | 2,240,623 | 269,731 | 12.0 |
| New Hampshire | 4,047,980 | 1,734,391 | 42.9 |
| New Jersey | 34,195,623 | 7,653,780 | 22.4 |
| New Mexico | 4,159,433 | 460,000 | 11.1 |
| New York | 48,952,729 | 19,862,442 | 40.6 |
| North Carolina | 24,949,161 | 6,637,949 | 26.6 |
| North Dakota | 5,417,705 | 1,221,934 | 22.5 |
| Ohio | 48,234,644 | 9,662,370 | 20.0 |
| Oklahoma | 10,721,964 | 3,816,771 | 35.5 |
| Oregon | 15,851,436 | 6,027,751 | 38.2 |
| Pennsylvania | 80,699,582 | 21,335,826 | 26.4 |
| Rhode Island | 2,414,704 | 1,286,659 | 53.2 |
| South Carolina | 9,810,758 | 2,414,061 | 24.5 |
| South Dakota | 12,116,778 | 1,755,652 | 14.5 |
| Tennessee | 11,659,311 | 2,862,010 | 24.6 |
| Texas | 56,022,344 | 6,657,132 | 11.9 |
| Utah | 3,909,295 | 834,191 | 21.4 |
| Vermont | 2,882,200 | 1,107,033 | 58.8 |
| Virginia | 15,143,391 | 4,757,083 | 31.5 |
| Washington | 17,564,039 | 5,123,747 | 29.2 |
| West Virginia | 12,546,208 | 2,974,998 | 23.7 |
| Wisconsin | 41,706,869 | 4,958,934 | 11.8 |
| Wyoming | 2,818,372 | 554,258 | 19.7 |
| | 931,886,835 | 225,427,013 | 24.2 |

### COMPARISON OF AVERAGE LICENSE FEES AND GASOLINE TAXES, 1921 AND 1923

The relation between motor vehicle revenues and highway expenditures having been established, it now remains to be seen in what manner the motor vehicle revenues are raised. Tables 4 and 5 and Figure 2 show, for the years 1921 and 1923, respectively, the average motor vehicle revenues per vehicle and the division of these revenues between license fees and gasoline taxes. In 1921 the license fees collected by the several States amounted to $122,269,072, covering a total registration of 10,422,670 motor vehicles, from which it appears that the average payment was $11.70

TABLE 4.—*Average license fees and gasoline taxes, 1921*

| State | Average motor vehicle revenues per vehicle | Average license fees per vehicle: Amount | Average license fees per vehicle: Percentage of motor vehicle revenues | Average gasoline tax per vehicle: Amount | Average gasoline tax per vehicle: Percentage of motor vehicle revenues |
|---|---|---|---|---|---|
| | | | | | *Per cent* |
| Alabama | $13.90 | $13.90 | 100 | | |
| Arizona | 10.85 | 5.50 | 51 | $5.35 | 49 |
| Arkansas | 15.20 | 12.70 | 89 | 2.50 | 11 |
| California | 10.00 | 10.00 | 100 | | |
| Colorado | 10.00 | 6.20 | 62 | 3.80 | 38 |
| Connecticut | 17.21 | 15.90 | 92 | 1.31 | 8 |
| Delaware | 17.50 | 17.50 | 100 | | |
| Florida | 10.40 | 7.50 | 72 | 2.90 | 28 |
| Georgia | 15.20 | 12.90 | 85 | 2.30 | 15 |
| Idaho | 16.40 | 16.40 | 100 | | |
| Illinois | 10.20 | 10.20 | 100 | | |
| Indiana | 6.10 | 6.10 | 100 | | |
| Iowa | 16.70 | 16.70 | 100 | | |
| Kansas | 4.85 | 4.85 | 100 | | |
| Kentucky | 17.25 | 14.00 | 81 | 3.25 | 19 |
| Louisiana | 5.80 | 5.80 | 100 | | |
| Maine | 12.90 | 12.90 | 100 | | |
| Maryland | 18.10 | 18.10 | 100 | | |
| Massachusetts | 13.10 | 13.10 | 100 | | |
| Michigan | 14.20 | 14.20 | 100 | | |
| Minnesota | 17.60 | 17.60 | 100 | | |
| Mississippi | 11.50 | 11.50 | 100 | | |
| Missouri | 7.20 | 7.20 | 100 | | |
| Montana | 14.00 | 10.10 | 72 | 3.90 | 28 |
| Nebraska | 11.90 | 11.90 | 100 | | |
| Nevada | 9.50 | 9.50 | 100 | | |
| New Hampshire | 20.80 | 20.80 | 100 | | |
| New Jersey | 14.50 | 14.50 | 100 | | |
| New Mexico | 23.50 | 8.80 | 37 | 14.70 | 63 |
| New York | 12.70 | 12.70 | 100 | | |
| North Carolina | 18.60 | 15.20 | 82 | 3.40 | 18 |
| North Dakota | 7.40 | 7.40 | 100 | | |
| Ohio | 9.60 | 9.60 | 100 | | |
| Oklahoma | 11.80 | 11.80 | 100 | | |
| Oregon | 27.60 | 19.70 | 71 | 7.90 | 29 |
| Pennsylvania | 14.90 | 13.70 | 92 | 1.20 | 8 |
| Rhode Island | 15.50 | 15.50 | 100 | | |
| South Carolina | 8.20 | 8.20 | 100 | | |
| South Dakota | 6.10 | 6.10 | 100 | | |
| Tennessee | 11.80 | 11.80 | 100 | | |
| Texas | 8.10 | 8.10 | 100 | | |
| Utah | 9.30 | 9.30 | 100 | | |
| Vermont | 17.90 | 17.90 | 100 | | |
| Virginia | 14.50 | 14.50 | 100 | | |
| Washington | 19.50 | 17.00 | 87 | 2.50 | 13 |
| West Virginia | 13.30 | 13.30 | 100 | | |
| Wisconsin | 10.80 | 10.80 | 100 | | |
| Wyoming | 10.70 | 10.70 | 100 | | |
| Average, States having gasoline tax | 16.14 | 13.40 | 83 | 2.74 | 17 |
| Average, all States | 12.20 | 11.70 | 96 | .50 | 4 |

per vehicle. In the same year 13 States collected $5,302,259 in gasoline taxes, which amounted to an average of 50 cents per motor vehicle for the country as a whole, or $2.74 per motor vehicle for those States in which the gasoline tax was in effect. If we divide the sum of all the license fees and the gasoline taxes by the total number of motor vehicles, we get an average of $12.20 paid by each vehicle. For those States which had the gasoline tax the average motor vehicle revenues were $16.14 per vehicle. The highest average payment per motor vehicle was in Oregon, where 71 per cent of the average payment of $27.60 was derived from license fees and 29 per cent from gasoline taxes. Kansas collected the lowest average revenue, or $4.85 per vehicle, which was wholly in license fees. In the same year the average motor vehicle revenue exceeded $20 in but three States—New Hampshire, New Mexico, and Oregon; in 34 States it was between $10 and $19, and in 11 States, less than $10.

In 1923, the last year for which full and complete data are available, the total license fees and permits, exclusive of the District of Columbia, amounted to $188,613.074 for a registration of 15,017,366 motor vehicles, or an average of $12.52 per vehicle. A gasoline tax was collected in 35 States, yielding a total of $36,813,939, which was an average payment of $4.90 for those States in which the tax was in effect. If the gasoline tax revenues are applied to the total registration of the country, the average payment per vehicle is reduced to $2.44. The total motor vehicle revenues of all the States represented an average of $14.96 per vehicle; if the 35 States which had in effect a gasoline tax are segregated, the motor vehicle revenues in those States averaged $16.60 per vehicle. In this year there were 15 States in which the motor vehicle revenues averaged $20 and over per vehicle; in 28 States the average ranged between $10 and $19; and in 5 States it was less than $10 per vehicle.

The average motor vehicle revenues for 1921 and 1923 can be compared thus:

| | 1921 | 1923 |
|---|---|---|
| States in which average revenues were $20 and over | 3 | 15 |
| States in which average revenues were $10 to $19 | 34 | 28 |
| States in which average revenues were $10 and less | 11 | 5 |

#### GASOLINE CONSUMPTION AND TAX RECEIPTS PER CAR FOR PERIOD, JANUARY 1 TO JULY 1, 1924

In the States which collected a gasoline tax during the first six months of 1924 the collections amounted to $4.18 per car (Table 6, fig. 3). The average consumption per car was 211.5 gallons. It is estimated that the year's consumption will average more than twice this amount because there will be more auto-

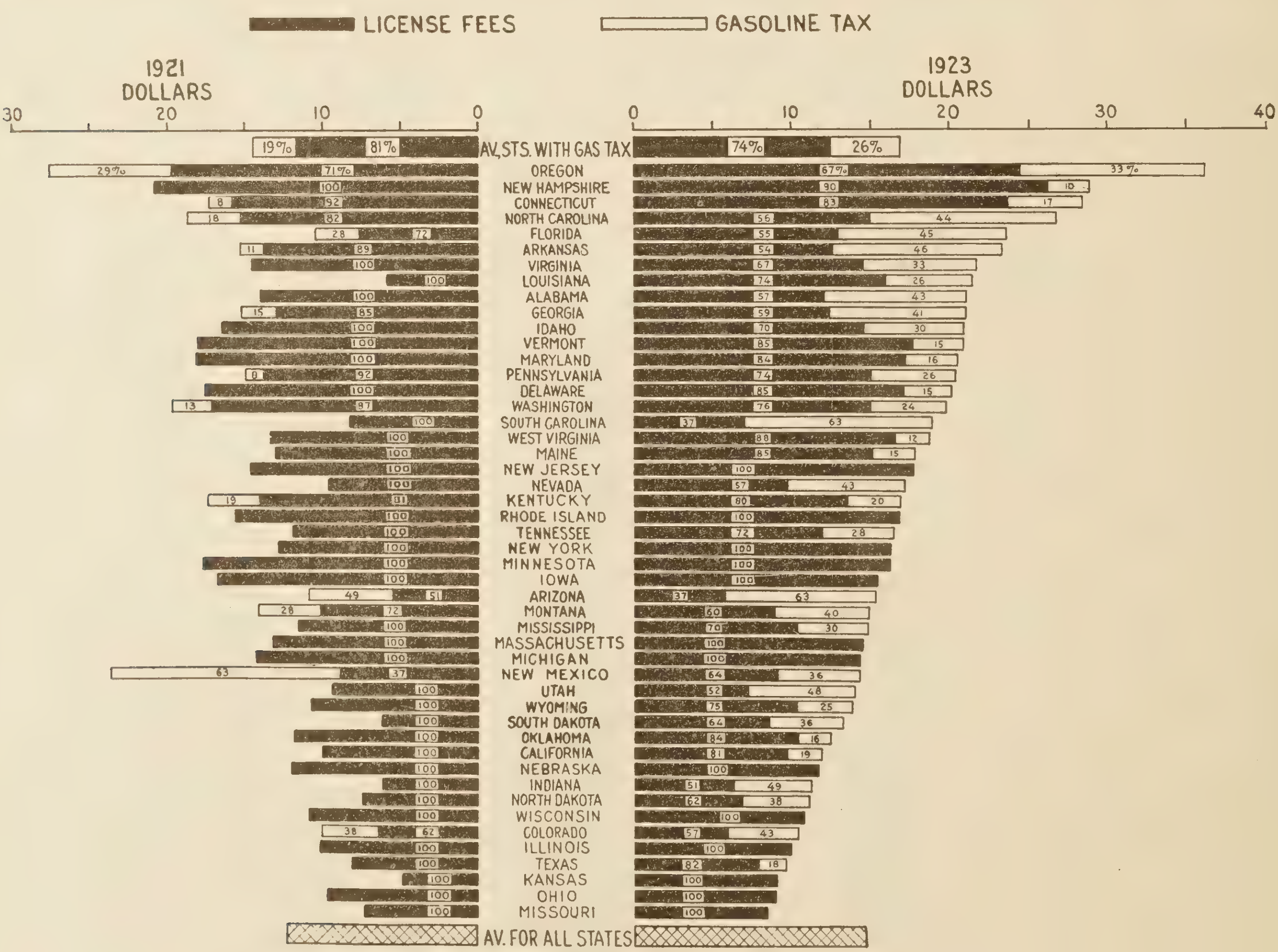


FIG. 2.—Average revenue per motor vehicle, 1921 and 1923

TABLE 5.—*Average license fees and gasoline taxes, 1923*

| State | Average motor-vehicle revenues per vehicle | Average license fees per vehicle | | Average gasoline tax per vehicle | |
|---|---|---|---|---|---|
| | | Amount | Percentage of motor-vehicle revenues | Amount | Percentage of motor-vehicle revenues |
| | | | *Per cent* | | *Per cent* |
| Alabama | $21.12 | $12.17 | 57 | $8.95 | 43 |
| Arizona | 15.37 | 5.73 | 37 | 9.64 | 63 |
| Arkansas | 23.43 | 12.67 | 54 | 10.76 | 46 |
| California | 11.93 | 9.64 | 81 | 2.29 | 9 |
| Colorado | 10.44 | 5.96 | 57 | 4.48 | 43 |
| Connecticut | 28.66 | 23.82 | 83 | 4.84 | 17 |
| Delaware | 20.17 | 17.22 | 85 | 2.95 | 15 |
| Florida | 23.72 | 12.92 | 55 | 10.80 | 45 |
| Georgia | 21.04 | 12.40 | 59 | 8.64 | 41 |
| Idaho | 21.00 | 14.65 | 70 | 6.35 | 30 |
| Illinois | 9.94 | 9.94 | 100 | | |
| Indiana | 11.31 | 6.33 | 56 | 4.98 | 44 |
| Iowa | 15.46 | 15.46 | 100 | | |
| Kansas | 9.15 | 9.15 | 100 | | |
| Kentucky | 16.93 | 13.50 | 80 | 3.43 | 20 |
| Louisiana | 21.56 | 16.04 | 74 | 5.52 | 26 |
| Maine | 17.92 | 15.29 | 85 | 2.63 | 15 |
| Maryland | 20.57 | 17.22 | 84 | 3.35 | 16 |
| Massachusetts | 14.53 | 14.53 | 100 | | |
| Michigan | 14.37 | 14.37 | 100 | | |
| Minnesota | 16.33 | 16.33 | 100 | | |
| Mississippi | 14.82 | 10.33 | 70 | 4.49 | 30 |
| Missouri | 8.43 | 8.43 | 100 | | |
| Montana | 14.86 | 9.88 | 60 | 5.98 | 40 |
| Nebraska | 11.72 | 11.72 | 100 | | |
| Nevada | 17.18 | 9.80 | 57 | 7.38 | 43 |
| New Hampshire | 29.10 | 26.36 | 90 | 2.74 | 10 |
| New Jersey | 17.76 | 17.76 | 100 | | |
| New Mexico | 14.36 | 9.21 | 64 | 5.15 | 36 |
| New York | 16.49 | 16.49 | 100 | | |
| North Carolina | 26.89 | 15.10 | 56 | 11.79 | 44 |
| North Dakota | 11.18 | 6.96 | 62 | 4.22 | 38 |
| Ohio | 9.04 | 9.04 | 100 | | |
| Oklahoma | 12.43 | 10.48 | 84 | 1.95 | 16 |
| Oregon | 36.32 | 24.52 | 67 | 11.80 | 33 |
| Pennsylvania | 20.44 | 15.18 | 74 | 5.26 | 26 |
| Rhode Island | 16.86 | 16.86 | 100 | | |
| South Carolina | 18.94 | 7.08 | 37 | 11.86 | 63 |
| South Dakota | 13.33 | 8.59 | 64 | 4.74 | 36 |
| Tennessee | 16.51 | 11.82 | 72 | 4.69 | 28 |
| Texas | 9.68 | 7.91 | 82 | 1.77 | 18 |
| Utah | 14.02 | 7.23 | 52 | 6.79 | 48 |
| Vermont | 20.98 | 17.79 | 85 | 3.19 | 15 |
| Virginia | 21.73 | 14.62 | 67 | 7.11 | 33 |
| Washington | 19.84 | 15.10 | 76 | 4.74 | 24 |
| West Virginia | 18.84 | 16.52 | 88 | 2.32 | 12 |
| Wisconsin | 10.84 | 10.84 | 100 | | |
| Wyoming | 13.92 | 10.40 | 75 | 3.52 | 25 |
| Average, States having gasoline tax | 16.60 | 11.70 | 71 | 4.90 | 29 |
| Average, all States | 14.96 | 12.52 | 84 | 2.44 | 16 |

mobile operation in the latter half of the year than in the first half by reason of the better road and weather conditions. So far as can be ascertained, the increasing of the gasoline-tax rate does not retard the sale of gasoline or the consumption per car. An exact comparison in the amount consumed per car per unit of time can not be made for all States because of the rate changes which took place at odd times and because of irregularities in reporting. In the case of Florida and Georgia, however, such a comparison is possible. Both had in effect a 1-cent rate during the first six months of 1923, and the average consumption of gasoline per car during that period was 318 gallons in Florida and 266 gallons in Georgia. With a 3-cent tax in effect during the first six months of 1924 the consumption in Florida was increased to 373 gallons per car, and in Georgia it was increased to 310 gallons per car. In Pennsylvania, South Dakota, and Washington the gasoline tax for the first six months of 1923 was 1 cent, and for the first six months of 1924 it was 2 cents. The average consumption per car for these same periods increased from 155 gallons to 162 gallons in Pennsylvania; from 136 gallons to 187 gallons in South Dakota; and from 178 gallons to 243 gallons in Washington.

TABLE 6.—*Gasoline consumption and gasoline-tax revenues per car, first six months of 1924*

| State | Gasoline consumption per car | Gasoline-tax revenues per car |
|---|---|---|
| | *Gallons* | |
| Alabama | 239 | $4.78 |
| Arizona | 220 | 6.60 |
| Arkansas | 210 | 8.40 |
| California | 253 | 5.06 |
| Colorado | 200 | 4.00 |
| Connecticut | 223 | 2.23 |
| Delaware | 192 | 3.84 |
| District of Columbia | 260 | 5.20 |
| Florida | 373 | 11.19 |
| Georgia | 310 | 9.30 |
| Idaho | 181 | 3.62 |
| Indiana | 181 | 3.62 |
| Kentucky | 163 | 4.89 |
| Louisiana | 285 | 2.85 |
| Maine | 150 | 1.50 |
| Maryland | 158 | 3.16 |
| Mississippi | 152 | 4.56 |
| Montana | 91 | 1.82 |
| Nevada | 145 | 2.90 |
| New Hampshire | 159 | 3.18 |
| New Mexico | 243 | 2.43 |
| North Carolina | 236 | 7.08 |
| North Dakota | 90 | .90 |
| Oklahoma | 172 | 4.30 |
| Oregon | 225 | 6.75 |
| Pennsylvania | 162 | 3.24 |
| South Carolina | 240 | 7.20 |
| South Dakota | 187 | 3.74 |
| Tennessee | 198 | 3.96 |
| Texas | 266 | 2.66 |
| Utah | 170 | 4.25 |
| Vermont | 114 | 1.14 |
| Virginia | 202 | 6.06 |
| Washington | 243 | 4.86 |
| West Virginia | 144 | 2.88 |
| Wyoming | 201 | 2.01 |
| Average | 211.5 | 4.18 |

### AVERAGE PASSENGER CAR AND MOTOR TRUCK FEES COMPARED FOR 28 STATES, FIRST SIX MONTHS, 1924

Comparison of passenger car and motor truck fees can be made for 28 States which, for the first six months of 1924, reported separately the license fees derived from passenger cars and from motor trucks and the number of each registered. The average passenger car license fee ranged from $3.17 in California to $28.20 in Idaho (Table 7, Fig. 4). The average for these States was $10.70, though it should be noted that in 17 of the States the average fees were larger than the average license fee for the 28 States as a whole.

The average motor truck license fee for these same States was $21.90, or more than twice as much as the average passenger car fee. The lowest average is found in Montana, where the average motor truck was charged only $11.60 for a license, and the highest is in Oregon, where the average was $51.80. In this case the average was also the mean; 14 of the States charged a license fee greater than the average, and 14 charged less. There is a marked tendency to charge higher license fees for motor trucks than for passenger cars even in those States where the average passenger car license fees are low. In the 11 States where the passenger car license fees are less than the average, or less than $10.70, the motor truck license fees are, on the average, 143 per cent higher; for the 18 States in which the average passenger car fees are above $10.70, the average motor truck fees are only 59 per cent higher.

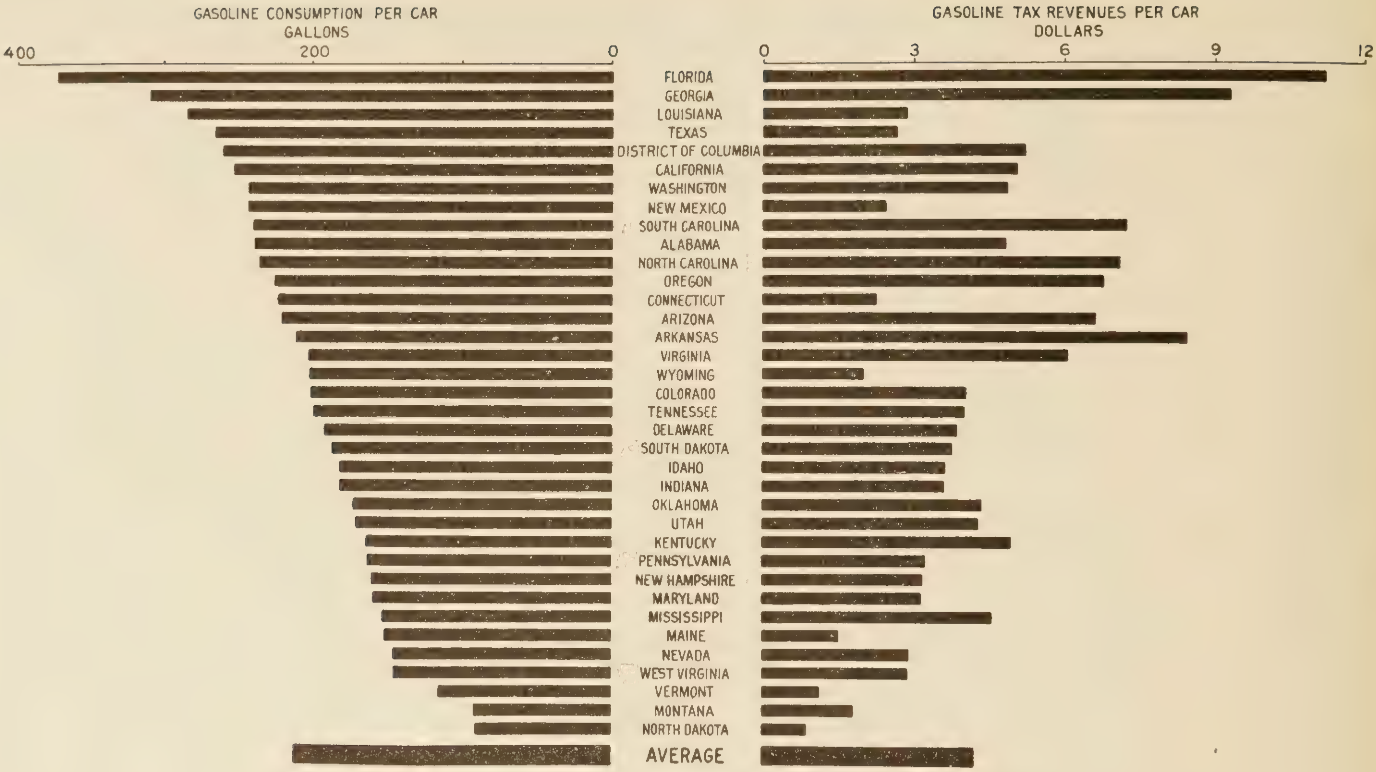


FIG. 3.—Gasoline taxes per car and gasoline consumption per car, first six months of 1924

TABLE 7.—*Average passenger car and motor truck license fees, first six months, 1924*

| State | Average passenger car fee | Average motor truck fee |
|---|---|---|
| California | $3.17 | $13.00 |
| Colorado | 5.31 | 12.35 |
| Connecticut | 16.45 | 34.30 |
| Delaware | 11.80 | 21.20 |
| Georgia | 12.25 | 16.60 |
| Idaho | 28.20 | 27.60 |
| Illinois | 8.90 | 19.25 |
| Indiana | 7.15 | 13.30 |
| Louisiana | 16.00 | 17.25 |
| Maryland | 7.55 | 23.70 |
| Massachusetts | 10.55 | 15.10 |
| Michigan | 12.85 | 17.70 |
| Minnesota | 16.20 | 25.30 |
| Montana | 9.48 | 11.60 |
| Nebraska | 11.15 | 19.50 |
| New Jersey | 9.80 | 28.65 |
| New Mexico | 8.80 | 22.80 |
| New York | 12.85 | 28.30 |
| Oregon | 24.10 | 51.80 |
| Pennsylvania | 10.40 | 29.70 |
| Rhode Island | 12.80 | 21.75 |
| South Carolina | 6.95 | 25.50 |
| South Dakota | 14.75 | 21.30 |
| Vermont | 18.70 | 25.90 |
| Virginia | 13.65 | 16.00 |
| Washington | 13.40 | 24.30 |
| West Virginia | 13.10 | 23.00 |
| Wisconsin | 11.80 | 22.10 |
| Average | 10.70 | 21.90 |

### AMOUNT OF MOTOR VEHICLE FEES AND GASOLINE TAX RECEIPTS APPLICABLE TO HIGHWAY WORK BY OR UNDER SUPERVISION OF STATE HIGHWAY DEPARTMENTS, 1923

Tables 8 and 9 show the gross motor vehicle license fees and gasoline tax receipts and the amounts which the several States devote to highway work under the direction of their State highway departments. The tabulations cover the year 1923. Of the $188,613,074 collected as motor vehicle license fees, $153,226,636, or 81 per cent, was used for highway work by the State highway departments. In 14 States 100 per cent of the license fees is turned over to the State highway departments, in 17 States the State highway department directs the expenditure of from 90 to 99 per cent, in 10 between 50 and 89 per cent, and in 7 States the amount of motor vehicle license fees applicable to highway work by or under supervision of State highway departments is between 10 and 49 per cent of the total collected in this manner.

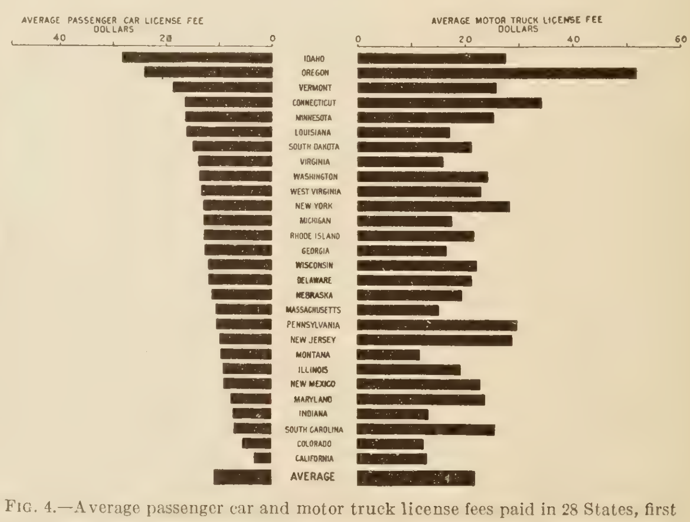


FIG. 4.—Average passenger car and motor truck license fees paid in 28 States, first six months of 1924

The gasoline tax receipts for 1923 were $36,813,939, of which amount the State highway departments directed the expenditure of $21,528,559, or only 58 per cent. In 13 States the State highway departments control the expenditure of all the gasoline tax receipts, in 5 States they control from 90 to 99 per cent, in 6 States 50 to 89 per cent, and in 8 they control less than 50 per cent. In 3 States, Alabama, North Dakota,

TABLE 8.—*Gross motor vehicle registration receipts and amounts applicable to highway work by or under the supervision of State highway departments, 1923*

| State | Gross registration receipts | Applicable to highway work by or under the supervision of State highway departments. | |
|---|---|---|---|
| | | Amount | Percentage of receipts |
| | | | *Per cent* |
| Alabama | $1, 541, 018 | $1, 204, 449 | 78 |
| Arizona | 281, 671 | 281, 671 | 100 |
| Arkansas | 1, 435, 090 | 430, 527 | 30 |
| California | 10, 608, 544 | 4, 906, 015 | 46 |
| Colorado | 1, 126, 219 | 534, 954 | 47 |
| Connecticut | 4, 329, 432 | 4, 329, 432 | 100 |
| Delaware | 516, 209 | 516, 209 | 100 |
| Florida | 1, 963, 066 | 1, 394, 529 | 71 |
| Georgia | 2, 156, 406 | 2, 095, 763 | 97 |
| Idaho | 914, 015 | 229, 840 | 25 |
| Illinois | 9, 653, 796 | 9, 653, 796 | 100 |
| Indiana | 3, 693, 715 | 3, 492, 498 | 95 |
| Iowa | 8, 827, 063 | 8, 000, 000 | 90 |
| Kansas | 3, 435, 606 | 1, 750, 000 | 51 |
| Kentucky | 2, 678, 733 | 2, 678, 733 | 100 |
| Louisiana | 2, 191, 241 | 2, 191, 241 | 100 |
| Maine | 1, 660, 268 | 1, 474, 383 | 89 |
| Maryland | 3, 536, 955 | 3, 183, 260 | 90 |
| Massachusetts | 6, 989, 633 | 6, 639, 155 | 95 |
| Michigan | 10, 500, 786 | 4, 741, 625 | 45 |
| Minnesota | 7, 316, 772 | 7, 316, 772 | 100 |
| Mississippi | 1, 077, 616 | 580, 852 | 54 |
| Missouri | 4, 016, 384 | 4, 016, 384 | 100 |
| Montana | 729, 621 | 73, 326 | 10 |
| Nebraska | 3, 353, 175 | 2, 932, 243 | 87 |
| Nevada | 153, 888 | 144, 992 | 94 |
| New Hampshire | 1, 571, 327 | 1, 464, 097 | 93 |
| New Jersey | 7, 653, 780 | 7, 515, 116 | 98 |
| New Mexico | 295, 000 | 280, 250 | 95 |
| New York | 19, 862, 442 | 14, 896, 831 | 75 |
| North Carolina | 3, 728, 045 | 3, 700, 000 | 99 |
| North Dakota | 760, 852 | 760, 444 | 100 |
| Ohio | 9, 662, 370 | 4, 832, 962 | 50 |
| Oklahoma | 3, 217, 771 | 2, 895, 000 | 90 |
| Oregon | 4, 069, 609 | 2, 924, 707 | 72 |
| Pennsylvania | 15, 844, 304 | 15, 844, 304 | 100 |
| Rhode Island | 1, 286, 659 | 1, 196, 909 | 93 |
| South Carolina | 902, 609 | 722, 087 | 80 |
| South Dakota | 1, 130, 959 | 1, 055, 176 | 93 |
| Tennessee | 2, 049, 653 | 2, 028, 806 | 99 |
| Texas | 5, 441, 509 | 2, 368, 569 | 43 |
| Utah | 430, 105 | 430, 105 | 100 |
| Vermont | 938, 860 | 860, 803 | 92 |
| Virginia | 3, 200, 162 | 3, 200, 162 | 100 |
| Washington | 3, 898, 598 | 3, 741, 168 | 96 |
| West Virginia | 2, 608, 508 | 2, 608, 508 | 100 |
| Wisconsin | 4, 958, 934 | 4, 693, 887 | 95 |
| Wyoming | 414, 096 | 414, 096 | 100 |
| | 188, 613, 074 | 153, 226, 636 | 81 |

and Pennsylvania the State highway departments do not receive any part of the gasoline tax receipts, nor do they have any supervision over their expenditure.

The revenues derived from license fees and gasoline taxes which are not turned over to State highway departments are usually divided among the counties or are credited to the general fund, from which they are again appropriated for highway work or for the payment of interest and the retirement of highway bonds. In only a few cases are the motor-vehicle revenues diverted to uses wholly foreign to road work.

#### RELATION OF HIGHWAY EXPENDITURES TO INCOME

In discussing the subject of highway expenditures the question is often raised as to the amount of money which the people of a State or a community can afford to spend for the improvement of the roads. The relationship which exists between the highway expenditures and the income of the people reduced to a per capita basis furnishes one criterion which can be applied.

In Table 10 are set forth by States the per capita highway expenditures exclusive of interest and principal payments, and the percentage ratios which these highway expenditures bear to the per capita incomes of the several States. In 13 States—Alabama, California, Connecticut, Illinois, Maryland, Massachusetts, Missouri, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont—the per capita highway expenditures in 1921 amounted to less than 1 per cent of each person's income; in 17 States—Colorado, Florida, Georgia, Kentucky, Louisiana, Maine, Michigan, Nebraska, New Mexico, Ohio, Oklahoma, Tennessee, Texas, Utah, Virginia, Washington, West Virginia—the highway expenditures were between 1 and 2 per cent of the income; in 11 States—Delaware, Indiana, Kansas, Minnesota, Montana, Nevada, North Carolina, North Dakota, South Carolina, Wisconsin, Wyoming—the highway expenditures were between 2 and 3 per cent; and in 7 States—Arizona, Arkansas, Idaho, Iowa, Mississippi, Oregon, South Dakota—they were over 3 per cent. South Dakota, where the highway expenditures amounted to 6.84 per cent of the people's income, showed the highest ratio; in New York, where the ratio is lowest, the highway expenditures were only 0.34 per cent of the income. In general, it may be said that where the per capita highway expenditures are large, there the ratio between such expenditures and the per capita income is also high. In States where there are large cities the per capita highway expenditures are low in general, while the per capita income is greater than in the State where the rural population dominates. In the New England and Middle Atlantic States the per capita expenditures for highway work averaged 0.55 per cent of the per capita income; the average for all

TABLE 9.—*Gross gasoline-tax receipts and amounts applicable to highway work by or under the supervision of State highway departments, 1923*

| State | Gross gasoline-tax receipts | Applicable to highway work by or under the supervision of State highway departments | |
|---|---|---|---|
| | | Amount | Percentage of receipts |
| | | | *Per cent* |
| Alabama | $1, 133, 085 | ---------- | ---------- |
| Arizona | 474, 123 | $118, 531 | 25 |
| Arkansas | 1, 219, 199 | 301, 095 | 25 |
| California | 2, 518, 893 | 1, 259, 446 | 50 |
| Colorado | 846, 353 | 402, 018 | 47 |
| Connecticut | 880, 223 | 880, 223 | 100 |
| Delaware | 88, 579 | 88, 579 | 100 |
| Florida | 1, 641, 042 | 1, 150, 356 | 70 |
| Georgia | 1, 502, 503 | 247, 666 | 16 |
| Idaho | 396, 487 | 396, 487 | 100 |
| Indiana | 2, 906, 428 | 2, 514, 756 | 86 |
| Kentucky | 680, 435 | 680, 435 | 100 |
| Louisiana | 754, 438 | 754, 438 | 100 |
| Maine | 286, 077 | 285, 840 | 100 |
| Maryland | 688, 304 | 688, 304 | 100 |
| Mississippi | 467, 855 | 187, 142 | 40 |
| Montana | 441, 249 | 75, 877 | 17 |
| Nevada | 115, 843 | 60, 000 | 52 |
| New Hampshire | 163, 065 | 161, 823 | 99 |
| New Mexico | 165, 000 | 156, 750 | 95 |
| North Carolina | 2, 909, 905 | 2, 900, 000 | 100 |
| North Dakota | 461, 082 | ---------- | ---------- |
| Oklahoma | 599, 000 | 599, 000 | 100 |
| Oregon | 1, 958, 141 | 1, 885, 421 | 96 |
| Pennsylvania | 5, 491, 523 | ---------- | ---------- |
| South Carolina | 1, 511, 453 | 411, 328 | 27 |
| Touth Dakota | 624, 692 | 565, 000 | 90 |
| Tennessee | 812, 357 | 801, 502 | 99 |
| Texas | 1, 215, 623 | 911, 717 | 75 |
| Utah | 404, 086 | 106, 903 | 26 |
| Vermont | 168, 173 | 168, 173 | 100 |
| Virginia | 1, 556, 921 | 1, 037, 947 | 67 |
| Washington | 1, 225, 150 | 1, 225, 150 | 100 |
| West Virginia | 366, 490 | 366, 490 | 100 |
| Wyoming | 140, 162 | 140, 162 | 100 |
| | 36, 813, 939 | 21, 528, 559 | 58 |

other sections of the country was over 1 per cent; and in the West North Central and the Mountain States it was over 2 per cent. These higher percentages represent the effort that is being made by small populations to bear the costs of extended highway improvement with relatively small income per capita.

TABLE 10.—*Per capita highway expenditures and ratio of expenditure to income, 1921*

| State | Highway expenditures per capita | Ratio of per capita highway expenditures to per capita income |
|---|---|---|
| | | *Per cent* |
| Alabama | $2.10 | 0.61 |
| Arizona | 29.30 | 3.86 |
| Arkansas | 11.10 | 3.52 |
| California | 10.70 | .74 |
| Colorado | 9.50 | 1.08 |
| Connecticut | 6.10 | .59 |
| Delaware | 25.00 | 2.76 |
| Florida | 8.80 | 1.55 |
| Georgia | 5.00 | 1.58 |
| Idaho | 25.00 | 4.03 |
| Illinois | 5.80 | .57 |
| Indiana | 15.10 | 2.56 |
| Iowa | 16.40 | 3.71 |
| Kansas | 12.60 | 2.15 |
| Kentucky | 4.80 | 1.05 |
| Louisiana | 6.60 | 1.32 |
| Maine | 10.70 | 1.34 |
| Maryland | 6.20 | .66 |
| Massachusetts | 4.80 | .40 |
| Michigan | 13.80 | 1.69 |
| Minnesota | 15.60 | 2.33 |
| Mississippi | 9.60 | 3.34 |
| Missouri | 4.50 | .71 |
| Montana | 16.90 | 2.85 |
| Nebraska | 8.00 | 1.43 |
| Nevada | 25.50 | 2.71 |
| New Hampshire | 11.70 | .92 |
| New Jersey | 8.40 | .77 |
| New Mexico | 9.40 | 1.79 |
| New York | 4.90 | .34 |
| North Carolina | 10.00 | 2.61 |
| North Dakota | 11.20 | 2.65 |
| Ohio | 11.30 | 1.40 |
| Oklahoma | 6.90 | 1.44 |
| Oregon | 33.80 | 3.90 |
| Pennsylvania | 7.90 | .84 |
| Rhode Island | 4.50 | .37 |
| South Carolina | 5.60 | 2.34 |
| South Dakota | 21.70 | 6.84 |
| Tennessee | 5.20 | 1.25 |
| Texas | 9.80 | 1.66 |
| Utah | 10.20 | 1.55 |
| Vermont | 6.10 | .82 |
| Virginia | 6.20 | 1.32 |
| Washington | 16.40 | 1.68 |
| West Virginia | 6.30 | 1.03 |
| Wisconsin | 15.50 | 2.17 |
| Wyoming | 22.30 | 2.23 |
| Average | 9.00 | 1.13 |

## RECOMMENDED INVESTIGATIONS IN THE FIELD OF MOTOR VEHICLE TAXES

The data available at this time relative to the whole subject of motor vehicle taxation are confined solely to the revenues obtained through license and registration fees and the gasoline tax. In a great many States the motor vehicle owner has to pay additional taxes on his car. In the first place, he is subject to a personal property tax on his car the same as any other kind of property, except in States where the legislature has provided specific exemption for the automobile from this kind of tax. So far as can be learned, there are now 13 States which do not levy a property tax on the motor vehicle—Delaware, Idaho, Iowa, Michigan, Minnesota, New Hampshire, New York, North Dakota, Oklahoma, Oregon, Pennsylvania, Tennessee, and Vermont. In these States the license fees are collected in lieu of property taxes. No definite figures have as yet been ascertained as to the amount of the general property taxes on automobiles for the country as a whole. The estimates which have been made show wide variations. It is frequently stated that even those States which tax the motor vehicle as property fail to a very considerable extent in collecting the taxes from all of the car owners. In many instances there does not appear to be any close relationship between the State motor vehicle registration office and the taxing authorities. To remedy this condition was the reason given in a number of the States for increasing license fees and exempting the automobile from the general property tax. To be able to show fully the extent to which the motorists contribute towards highway expenditures, it is necessary to make further inquiries into this subject of the taxation of the motor vehicle as property.

In the second place, motorists in many cities are obliged to pay special municipal license fees, sometimes known as "wheelage taxes." In some cases they amount to more than the State license fees. It is therefore of importance to collect data as to the amount of revenues derived from the automobile in this manner and the use to which such funds are put.

Further investigations should also be made with reference to the distribution of license fees and gasoline taxes as between State highway authorities and local governmental units. Municipalities, in some instances, already are claiming a share of the gasoline taxes. In order to work out some fundamental principles regarding the allocation of such revenues, it is necessary to determine more fully than has yet been done the relative use which city-owned motor vehicles make of our rural highways as compared with rural cars, and data should be collected further which will show the proportion of the total motor vehicle mileage which occurs within city limits as compared with the rural highway mileage. Such facts will be of use in the development of apportionment principles.

The effect which improved and hard-surfaced roads have on values of adjacent farm lands constitutes a problem which is of special interest to one studying this subject of the equitable apportionment of the highway finance burden. There are now under way several researches inaugurated by the Bureau of Public Roads in cooperation with State bodies, which it is expected will provide certain fundamental data which will be of value in determining how much real property in the rural sections should contribute towards highway improvement.

There is no doubt that many of the State legislatures will find it necessary in the next few years to revise and expand their highway laws and to provide more adequately for contemplated highway improvements. In order that such legislative work may be done according to sound economic principles and in harmony with good public policy, it behooves those who are interested in these subjects to procure and interpret all the underlying facts of highway finance so that they may be available to all who seek guidance and knowledge therefrom.

# HIGHWAY TRANSPORTATION COURSES THEIR PLACE AND CONTENT

By CHARLES LEE RAPER, Franklin Professor of Transportation, and Dean of the College of Business Administration, Syracuse University

I BELIEVE it is correct to ask a college to offer a course in any subject which has large importance in the life of a community. If this be a correct basis for a college course, transportation should have at least one course in many of our colleges. To transport people and their products is equally as important as the production of their goods or the development of their surroundings. The movement of people and their products is an essential function of civilized life. A college should, in my judgment, offer courses dealing with the essential functions of life.

Many colleges give some attention, in a general way, to the value of transportation. Some of them give specific attention to transportation by rail or by water. Upon the basis of relative importance, highway transportion deserves a place in the college courses. The traffic which moves over the highways is at least large enough to entitle it to be compared with the traffic which moves over the railways or the waterways. People are transporting themselves more and more over their highways by horse vehicle or motor car, and I am convinced that this process will continue to grow. They are sending their commodities in ever greater quantity over the highways. The highway is, and always will be, a very important form of transportation. To construct more of this form of transportation and to keep it ever in service—this constitutes one of the big tasks of our day, and we have no doubt that our children's children will think of it as one of their great tasks.

The coming of rapid transportation, on rail or water, has been one of the revolutionary things in modern life. It has made new things; it has remade old things. The building of efficient highways for use by animal-drawn vehicles, and especially for motor-driven vehicles, may well prove itself a thing of revolutionary force.

### HIGHWAY TRANSPORTATION BOTH AN ENGINEERING AND A BUSINESS PROPOSITION

The construction, maintenance, and use of the highway constitute both an engineering and a business proposition. The construction and maintenance are primarily questions of engineering. The use of the highway is essentially a business question. The construction and maintenance of the highway involve much cost, and the financing of this cost is a business problem, whether this be done by a corporation or by the State. The operation of vehicles upon the highway is primarily a matter of business for the individual or group of individuals. Highway transportation courses should, therefore, cover both the engineering aspects and the business aspects.

The location and construction of the highways should be given in the engineering group of courses rather than in the business administration group. The cost of the roads and their effect upon the movement of people and goods should, I think, be considered to some degree in the engineering courses.

The use of the highway and the traffic which moves upon it should be considered by the business administration group of courses. The vehicle and its performance are essentially business problems, even though these affect the location, construction, and maintenance of the highway. Both the highway and the vehicle must be considered, I believe, to some degree in both groups of courses—the engineering group and the business administration group.

The location, construction, and maintenance of the highway are essentially things of public interest. The use of the highway is, on the other hand, more largely a matter of private interest. How much of the cost of construction and maintenance should be borne by the users of the road and how much by the taxpayers should be adequately considered in any course in highway transportation. I think this is particularly true with the courses offered by the business administration group.

The question as to whether the vehicle which uses the highway should be defined in law as a public carrier and should, therefore, be held responsible for its services as a public carrier, even though its owner is an individual or corporate citizen, is also a fundamental one and must be considered in any course in highway transportation.

### OPERATION OF HIGHWAY TRANSPORTATION

The establishment and operation of a vehicle service on the highway should be considered more particularly as a private interest. For this reason any course offered in the business administration group should give careful and somewhat detailed consideration to at least the following aspects:

*The vehicle.*—The kind of vehicle, its size, weight, or tonnage capacity, constitute an important problem or series of problems for the operator of the vehicle and for the public. All of these aspects have large influence upon the owner's profits and also upon the cost of the construction and maintenance of the highway, as well as upon the safety of those who use the highway.

*The routing of the vehicle.*—The routing of the vehicle is primarily a business question, and it is of large importance. Upon the solution of this question depends, to a large degree, the prosperity of the operator of the vehicle. It is necessary that the routing of a vehicle be decided upon after a careful survey of the traffic from the point of view of the present and the future. It should also be decided upon after a study of the roads, actual and potential, and the amount of competition. The problem of the routing of a vehicle, as well as that of its size, weight, and tonnage capacity, should have adequate consideration in any course in highway transportation offered in a college of business administration.

*The cost system for operation and maintenance of the vehicle.*—Not only is it necessary for the operator of the vehicle to give his best attention to the vehicle and to its routing, but it is also necessary that he give his best attention to his cost system. Any course in highway transportation given in a college of business administration should, I think, devote considerable attention to a study of the cost systems for highway vehicle operators.

*Rates for the service.*—Rates for highway transportation services are as fundamentally important as rates for any other carrier or as prices for any other business. It should be clear to the users of the highway vehicles as well as to their operators that the rates should be large enough to cover all the items of cost of operation and to provide something for profits. Any course in highway transportation which may be offered by a college of business administration should go into a study of rates with no little emphasis. The following factors in rate making should at least have proper consideration:

1. Adequate interest on the investment in the highway vehicle.
2. Adequate depreciation of the vehicle and its auxilliary equipment.
3. Adequate provision for the maintenance of the vehicle.
4. Proper provision for taxes and license fees, which should be paid to the State for the use of the highway.
5. The cost of operation, including insurance on vehicle and traffic, supervision, etc.

*The competition of highway transportation.*—The rates for the highway service and the type of the service should always be considered in connection with the competition of this service with that of other carriers—as, for example, railways. This should be done for the sake of the business interest of the highway operator and for the sake of the public. The public now carefully regulates railway service. It should also regulate, in a large measure, the highway service. Both the highway service and the railway service should work in the largest possible cooperation. Sharp competition between these two types of transportation is injurious to both carriers and the public.

The contents of a highway transportation course, as they have been enumerated, might seem to suggest a very considerable value toward graduation. I believe that they can be adequately treated in a three-hour course for one-half of a college year. This is, of course, upon the assumption that the student has had effective training in the more general aspects of economics and politics.

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NOTE.—Contributed to the round-table conference on highway economics at the meeting of the American Economic Association, Chicago, Ill., December 30, 1924.

# 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 or 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.*

Report of the Chief of the Bureau of Public Roads, 1924.

## 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.
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. 25c.
*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. 10c.
*704. Typical Specifications for Nonbituminous Road Materials. 5c.
*724. Drainage Methods and Foundations for County Roads. 20c.
*1077. Portland Cement Concrete Roads. 15c.
*1132. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.
No. 1216. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1259. Standard Specifications for Steel Highway Bridges adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.

## DEPARTMENT CIRCULAR

No. 94. TNT as a Blasting Explosive.

## FARMERS' BULLETINS

No. *338. Macadam Roads. 5c.
*505. Benefits of Improved Roads. 5c.

## 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.

## 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. 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.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

# STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

## DECEMBER 31, 1924

| STATES | FISCAL YEARS 1917-1925 | | | FISCAL YEAR 1925 | | | | | | | | | BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS | STATES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PROJECTS COMPLETED PRIOR TO JULY 1, 1924 | | | PROJECTS COMPLETED SINCE JUNE 30, 1924 | | | *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 | $ 4,598,721.63 | $ 2,186,247.54 | 464.1 | $ 766,721.98 | $ 380,609.23 | 85.3 | $ 15,433,392.54 | $ 7,486,096.43 | 849.7 | $ 79,416.15 | $ 39,708.07 | 0.4 | $ 1,160,401.73 | Alabama |
| Arizona | 8,338,365.41 | 4,287,683.88 | 527.8 | 713,173.87 | 406,825.70 | 37.5 | 1,757,774.35 | 1,064,861.24 | 150.4 | 900,984.42 | 550,592.13 | 70.5 | 1,185,738.05 | Arizona |
| Arkansas | 11,094,751.31 | 4,424,345.63 | 944.4 | 1,637,568.79 | 688,383.74 | 68.1 | 6,453,537.33 | 2,651,817.83 | 339.6 | 922,438.41 | 429,429.67 | 74.6 | 868,423.13 | Arkansas |
| California | 12,999,075.03 | 5,647,148.17 | 533.7 | 4,463,144.73 | 2,347,870.47 | 177.3 | 11,194,859.15 | 5,768,442.68 | 359.2 | 491,988.13 | 287,811.77 | 1.9 | 3,042,032.91 | California |
| Colorado | 8,108,070.31 | 4,029,898.97 | 502.6 | 880,626.15 | 444,393.39 | 47.6 | 5,398,940.61 | 2,937,913.88 | 212.0 | 62,776.78 | 35,229.34 | 5.8 | 2,112,445.42 | Colorado |
| Connecticut | 3,062,872.02 | 1,269,558.60 | 73.6 | 199,024.56 | 98,423.00 | 4.9 | 3,262,054.48 | 1,045,804.04 | 54.1 | | | | 967,409.36 | Connecticut |
| Delaware | 3,056,832.22 | 1,007,714.83 | 72.5 | 462,969.09 | 197,825.82 | 13.8 | 1,316,585.49 | 504,231.10 | 33.1 | | | | 29,758.25 | Delaware |
| Florida | 961,134.07 | 461,470.92 | 48.8 | 1,415,010.74 | 681,331.64 | 25.4 | 8,274,647.58 | 4,060,548.44 | 236.4 | 398,642.71 | 171,123.94 | 10.3 | 912,412.06 | Florida |
| Georgia | 17,167,373.32 | 7,955,805.20 | 1,214.2 | 1,587,490.88 | 765,094.39 | 138.3 | 10,735,267.33 | 5,121,998.59 | 763.6 | 820,931.13 | 379,916.19 | 39.0 | 227,082.63 | Georgia |
| Idaho | 8,181,697.92 | 4,092,395.52 | 506.8 | 243,867.57 | 139,962.62 | 18.7 | 2,549,392.79 | 1,530,324.99 | 171.9 | 449,282.31 | 292,976.38 | 29.9 | 622,052.49 | Idaho |
| Illinois | 26,964,706.06 | 12,279,546.33 | 804.7 | 3,588,061.46 | 1,761,750.91 | 109.8 | 13,539,290.92 | 6,724,129.81 | 469.4 | 53,063.82 | 26,531.91 | 2.0 | 2,644,533.04 | Illinois |
| Indiana | 7,577,444.16 | 3,655,540.97 | 225.7 | 2,427,983.86 | 1,155,095.08 | 83.6 | 14,873,492.00 | 7,295,074.86 | 475.3 | | | | 2,206,681.09 | Indiana |
| Iowa | 23,195,778.19 | 9,237,031.86 | 1,682.9 | 1,986,999.59 | 899,447.75 | 157.7 | 7,146,594.05 | 3,264,649.47 | 501.9 | 2,098,815.48 | 900,900.00 | 78.9 | 1,034,107.92 | Iowa |
| Kansas | 17,084,136.48 | 6,043,176.80 | 502.7 | 5,234,527.81 | 2,014,461.76 | 159.4 | 14,772,222.66 | 5,939,501.97 | 623.5 | 2,808,795.68 | 1,295,068.71 | 151.5 | 7,079.76 | Kansas |
| Kentucky | 10,822,980.31 | 4,613,947.28 | 429.4 | 1,992,917.60 | 801,849.65 | 71.8 | 8,167,464.30 | 3,744,306.32 | 313.4 | 373,194.00 | 153,936.89 | 13.0 | 1,057,698.86 | Kentucky |
| Louisiana | 8,488,463.18 | 3,636,143.36 | 661.2 | 1,358,277.16 | 662,014.97 | 127.1 | 4,808,164.95 | 2,389,108.72 | 284.0 | 309,676.07 | 154,838.03 | 1.6 | 423,336.92 | Louisiana |
| Maine | 6,911,058.78 | 3,299,935.38 | 230.7 | 719,052.70 | 343,786.54 | 30.3 | 1,298,297.12 | 622,267.36 | 44.6 | | | | 823,982.72 | Maine |
| Maryland | 6,760,044.42 | 3,213,321.78 | 243.2 | 358,411.02 | 179,205.49 | 16.4 | 2,801,989.31 | 1,199,249.89 | 85.3 | 171,075.41 | 52,750.00 | 4.2 | 4,422.84 | Maryland |
| Massachusetts | 10,191,202.02 | 4,105,727.22 | 232.8 | 318,961.44 | 111,675.42 | 5.2 | 6,467,832.90 | 2,053,941.50 | 105.7 | 475,794.54 | 161,122.03 | 9.2 | 1,487,313.83 | Massachusetts |
| Michigan | 13,434,135.07 | 6,060,612.23 | 494.5 | 715,646.16 | 349,246.07 | 29.1 | 15,805,464.85 | 7,476,927.56 | 534.6 | | | | 1,992,986.14 | Michigan |
| Minnesota | 24,037,561.24 | 9,885,843.07 | 2,292.0 | 6,121,718.17 | 2,724,798.97 | 421.3 | 6,354,043.15 | 2,605,800.00 | 640.7 | 904,876.83 | 99,800.00 | 100.1 | 2,176.96 | Minnesota |
| Mississippi | 7,888,193.89 | 3,828,941.39 | 655.0 | 1,466,853.97 | 694,789.48 | 99.1 | 8,176,190.45 | 4,081,320.47 | 481.7 | 740,381.06 | 370,190.51 | 60.3 | 556,031.15 | Mississippi |
| Missouri | 11,352,027.70 | 5,245,899.18 | 803.5 | 1,326,969.31 | 654,897.27 | 100.6 | 23,384,211.22 | 10,198,390.71 | 878.0 | 3,849,064.62 | 1,104,000.14 | 141.8 | 737,000.70 | Missouri |
| Montana | 8,867,279.16 | 4,384,335.12 | 791.4 | 911,797.03 | 637,863.31 | 91.3 | 2,245,492.02 | 1,661,934.43 | 200.5 | 1,038,200.22 | 590,707.66 | 117.2 | 3,691,576.48 | Montana |
| Nebraska | 7,876,337.16 | 3,714,691.69 | 1,440.4 | 382,998.91 | 178,915.75 | 27.0 | 7,880,402.23 | 3,857,680.61 | 831.6 | 916,341.27 | 458,170.60 | 109.1 | 3,241,487.45 | Nebraska |
| Nevada | 3,460,245.52 | 1,853,624.98 | 225.6 | 1,102,421.45 | 928,932.16 | 92.2 | 4,584,901.22 | 3,867,650.75 | 399.1 | 38,940.11 | 32,787.34 | 2.0 | 207,325.77 | Nevada |
| New Hampshire | 3,076,750.19 | 1,487,867.58 | 171.3 | 767,036.04 | 352,053.17 | 27.3 | 1,015,014.26 | 478,844.00 | 31.6 | 29,611.26 | 13,680.00 | 0.9 | 102,519.25 | New Hampshire |
| New Jersey | 7,623,795.12 | 2,661,531.49 | 148.7 | 1,613,608.11 | 445,405.00 | 25.8 | 9,024,368.54 | 2,667,236.24 | 64.0 | | | | 815,074.27 | New Jersey |
| New Mexico | 5,306,286.45 | 2,758,849.68 | 714.3 | 912,328.07 | 559,290.38 | 84.7 | 6,656,272.99 | 4,386,862.23 | 666.1 | 250,983.39 | 154,354.77 | 16.7 | 729,974.94 | New Mexico |
| New York | 18,862,742.49 | 8,257,844.44 | 572.7 | 1,675,708.28 | 673,352.21 | 48.3 | 30,276,154.84 | 11,395,122.88 | 673.4 | 5,594,338.00 | 1,567,205.00 | 101.5 | 4,814,623.47 | New York |
| North Carolina | 12,567,732.97 | 5,676,757.66 | 884.7 | 3,582,873.35 | 1,217,143.39 | 95.9 | 8,717,966.68 | 3,509,481.05 | 244.5 | 1,437,527.05 | 669,797.82 | 52.1 | 1,221,071.08 | North Carolina |
| North Dakota | 9,088,973.11 | 4,418,505.42 | 1,587.9 | 1,296,143.59 | 631,116.50 | 264.8 | 2,994,655.33 | 1,502,937.30 | 407.8 | 295,074.10 | 147,537.01 | 27.2 | 1,663,559.77 | North Dakota |
| Ohio | 33,122,751.43 | 11,879,917.99 | 962.5 | 3,530,795.03 | 1,357,034.24 | 96.1 | 12,676,796.19 | 4,693,490.80 | 357.1 | 1,402,203.38 | 529,000.00 | 40.5 | 1,680,720.97 | Ohio |
| Oklahoma | 12,986,865.26 | 5,888,852.03 | 497.3 | 2,082,033.66 | 1,016,086.84 | 92.1 | 8,041,755.84 | 3,838,019.43 | 340.7 | 2,638,022.45 | 1,029,676.18 | 145.9 | 764,068.52 | Oklahoma |
| Oregon | 12,082,873.17 | 5,819,093.79 | 655.6 | 1,209,085.39 | 707,463.39 | 95.4 | 2,835,166.45 | 1,663,370.68 | 140.9 | 239,530.50 | 110,954.29 | 9.3 | 205,276.85 | Oregon |
| Pennsylvania | 36,825,248.98 | 14,114,694.79 | 729.7 | 1,675,929.93 | 740,322.44 | 38.6 | 22,786,424.84 | 6,088,062.50 | 374.6 | 3,143,714.81 | 887,575.00 | 58.8 | 2,770,961.27 | Pennsylvania |
| Rhode Island | 1,774,397.25 | 779,227.96 | 46.0 | 744,122.20 | 309,710.13 | 16.7 | 1,295,720.34 | 371,918.84 | 17.9 | | | | 472,184.07 | Rhode Island |
| South Carolina | 9,016,476.73 | 4,124,045.22 | 924.4 | 1,588,812.61 | 730,417.82 | 236.3 | 5,447,226.87 | 2,224,762.61 | 361.4 | 963,573.52 | 175,677.28 | 91.9 | 432,643.07 | South Carolina |
| South Dakota | 8,674,597.86 | 4,244,636.27 | 989.8 | 1,957,845.88 | 1,042,131.02 | 298.2 | 6,942,471.71 | 3,349,284.11 | 929.3 | 244,890.99 | 16,103.39 | 46.1 | 66,525.21 | South Dakota |
| Tennessee | 6,805,683.35 | 3,313,936.07 | 259.6 | 4,660,828.80 | 2,300,390.95 | 161.0 | 11,845,838.75 | 5,364,964.13 | 404.1 | 1,141,855.70 | 570,929.32 | 75.3 | 474,416.53 | Tennessee |
| Texas | 42,341,998.56 | 16,190,624.91 | 3,122.8 | 5,220,993.23 | 2,044,321.25 | 347.0 | 23,948,858.76 | 9,700,550.27 | 1,457.1 | 5,100,820.57 | 2,173,554.55 | 332.0 | 1,615,162.02 | Texas |
| Utah | 3,304,423.75 | 1,895,805.92 | 219.0 | 1,172,195.60 | 722,070.17 | 124.1 | 4,261,594.27 | 2,806,774.61 | 245.2 | 322,811.39 | 221,330.96 | 27.1 | 470,491.34 | Utah |
| Vermont | 1,922,114.16 | 942,769.12 | 74.4 | 152,908.38 | 76,454.18 | 6.3 | 2,104,686.81 | 996,894.18 | 51.4 | 53,364.64 | 26,682.31 | 1.4 | 491,179.21 | Vermont |
| Virginia | 10,035,301.48 | 4,801,782.43 | 562.5 | 1,266,937.26 | 592,715.20 | 55.1 | 9,615,581.51 | 4,465,484.83 | 326.1 | 1,119,227.82 | 508,734.98 | 38.6 | 224,235.56 | Virginia |
| Washington | 11,384,615.67 | 5,290,895.45 | 457.0 | 927,406.97 | 405,402.07 | 46.3 | 3,439,900.87 | 1,615,300.00 | 130.9 | 265,662.59 | 132,600.00 | 12.4 | 442,480.48 | Washington |
| West Virginia | 5,489,747.96 | 2,365,041.63 | 255.6 | 1,555,196.35 | 716,620.21 | 55.6 | 4,473,244.28 | 1,945,014.09 | 143.1 | 77,099.55 | 27,448.00 | 0.4 | 700,008.17 | West Virginia |
| Wisconsin | 18,753,903.15 | 7,441,033.57 | 1,325.3 | 1,324,722.32 | 628,581.41 | 61.7 | 4,007,979.67 | 1,933,333.37 | 166.3 | 135,408.28 | 67,703.00 | 7.2 | 3,607,799.65 | Wisconsin |
| Wyoming | 6,127,625.61 | 3,078,098.70 | 687.6 | 1,531,342.21 | 935,575.29 | 148.2 | 3,891,144.34 | 2,423,252.08 | 264.6 | | | | 250,424.93 | Wyoming |
| Hawaii | | | | | | | | | | | | | 365,625.00 | Hawaii |
| TOTALS | $549,655,391.27 | $237,852,399.82 | 32,452.9 | $82,832,049.26 | $ 38,453,007.84 | 4,664.3 | $394,971,329.14 | $176,574,933.88 | 17837.4 | $42,360,399.14 | $ 16,618,135.17 | 2,108.6 | $ 55,626,523.29 | TOTALS |

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 109,511,199.84 Federal aid $ 48,628,269.57 Miles 4,550.6