PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 20, NO. 8 ▽ OCTOBER 1939

ON US 395 IN NEVADA

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸▸▸ A Journal of Highway Research

Issued by the

FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 20, No. 8 October 1939

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

THE PUBLIC ROADS ADMINISTRATION - - - - - - - - - Willard Building, Washington, D.C.

REGIONAL HEADQUARTERS - - - - - - - - - - - - - Federal Building, Civic Center, San Francisco, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
Federal Building, Civic Center, San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
254 New Customhouse, Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
907 Post Office Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
711 U. S. Courthouse, Kansas City, Mo.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Room 502, United States Courthouse, Fort Worth, Tex.

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, and Tennessee.
Post Office Building, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
505 Post Office Building, Albany, N.Y.

DISTRICT No. 10. Delaware, Maryland, Ohio, Pennsylvania, and District of Columbia.
Willard Building, Washington, D.C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah.

DISTRICT No. 14. North Carolina, South Carolina, Virginia, and West Virginia.
Montgomery Building, Spartanburg, S.C.

DESIGN OF A FILL SUPPORTED BY CLAY UNDERLAID BY ROCK

AN APPLICATION OF SOIL MECHANICS IN SOLVING A HIGHWAY FILL PROBLEM

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by L. A. PALMER, Associate Chemist

THIS REPORT is a continuation of the theoretical considerations contained in two previous publications.[1,2] Its purpose is to present in usable form the analytical methods based on the assumption of conditions of plane strain [2] and to extend these analyses to include the problem of determining the supporting power of a clay stratum supporting a symmetrical earth fill when the clay stratum is underlaid by rock.

As shown in one of the previous publications [2] a problem involving plane strain conditions is one involving two dimensions. The load is distributed over an area that is quite long as compared to its width and the analytical procedure is applied to a vertical cross section of unit thickness in the direction of the longitudinal axis of the load. This is taken as the Y direction. It is considered that there is no displacement of material in this direction and that whatever soil movements occur are in the Z direction, which is toward the center of the earth, and in the X or horizontal direction, that is, perpendicular to both the Y and Z directions.

The analytical procedures used in the theoretical solution of the present problem involve two theories, that of elasticity and that of plastic equilibrium, and four principal assumptions are involved. The first three are common to both theories. The fourth is made only when the theory of plastic equilibrium is applied. These are:

1. The strength of the clay stratum depends essentially on its cohesion. The strength due to the element of friction is comparatively small and may be neglected. Hence, whenever and wherever the unit shearing stress becomes equal to the unit cohesion, c, the soil becomes plastic and undergoes plastic flow; that is, the soil fails.

2. The adhesion of the clay to the rock surface is "perfect." No slippage occurs at this surface although there may be lateral movement in the clay at points very near the rock surface.

3. The soil deformations considered in this paper are those that occur at an assumed constant volume. It seems reasonable to assume that the deformations caused by lateral yield in the X direction occur during a period of time that is brief in comparison with the time required for an appreciable degree of consolidation of the stressed clay stratum. When deformations occur at constant volume, Poisson's ratio is taken as $\frac{1}{2}$ (the approximate value).

4. In applying the method of plastic equilibrium it is considered that the fill acts like an absolutely rigid body in its production of stresses in the clay stratum when the soil is in the plastic state. Thus the fill above and the solid rock boundary below the clay constitute a "nutcracker."

[1] Principles of Soil Mechanics Involved in Fill Construction, L. A. Palmer and E. S. Barber, Proceedings Highway Research Board, Annual Meeting 1937.
[2] Principles of Soil Mechanics Involved in the Design of Retaining Walls and Bridge Abutments, L. A. Palmer, PUBLIC ROADS, vol. 19, No. 10, December 1938.

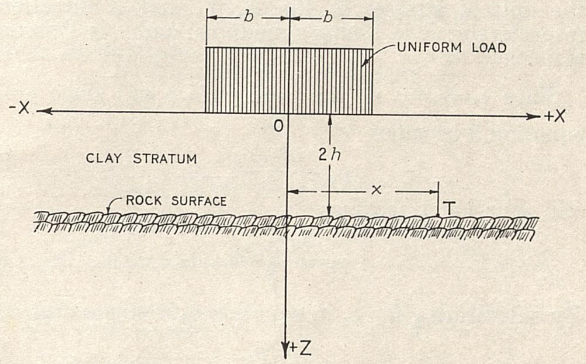

FIGURE 1.—UNIFORM LOAD ON A LONG STRIP SUPPORTED BY CLAY UNDERLAID BY SOLID ROCK.

Probably the fourth assumption is the least valid of the four.

Since it is assumed that there is no displacement either in the fill or in the supporting soil in the direction of the longitudinal (Y) axis of the fill, the problem is one of plane strain. One vertical cross section perpendicular to the Y axis is the same as any other insofar as stresses and deformations are concerned, assuming, of course, that both the fill material and the supporting clay are, in themselves, homogeneous. Since the rock is supposedly rigid, it follows that there is no vertical displacement of soil at this boundary.

STRESSES IN THE CLAY COMPUTED FROM THEORY OF ELASTICITY

Carothers [3] has shown that for a uniform load p per unit area on a long strip of width $2b$ (see fig. 1) at the surface, the shearing stress, s_{xz}, at the rock surface is

$$s_{xz}=\frac{p}{2}\left[\operatorname{sech}\frac{\pi}{2}\frac{x-b}{2h}-\operatorname{sech}\frac{\pi}{2}\frac{x+b}{2h}\right] \text{------} \quad (1)$$

where $2h$ is the thickness of the intervening clay layer.

This expression for s_{xz} for uniform strip loading and other expressions for stresses for other types of surface loading (see for example equation 12) are developed from the theory of elasticity. When these expressions are used it is considered that the clay mass has not been stressed to its ultimate supporting power and is therefore not reduced to a plastic condition throughout.

In the following discussion equations 2, 3, 4, and 8 are those frequently seen in texts on the theory of elasticity.[4]

[3] Test Loads on Foundations as Affected by Scale of Tested Area, S. D. Carothers, Proceedings International Mathematical Congress, Toronto, 1924, pp. 527–549.
[4] See, for example, pp. 8–20, inclusive, of Theory of Elasticity, by S. Timoshenko. McGraw-Hill Book Co., 1st. ed., 1934.

The fundamental strain relations are

$$\epsilon_x=\frac{1}{E}\Big[p_x-\mu(p_y+p_z)\Big] \text{------------} (2)$$

$$\epsilon_y=\frac{1}{E}\Big[p_y-\mu(p_x+p_z)\Big] \text{------------} (3)$$

$$\epsilon_z=\frac{1}{E}\Big[p_z-\mu(p_x+p_y)\Big] \text{------------} (4)$$

where ϵ_x, ϵ_y, and ϵ_z are the strains and p_x, p_y, and p_z are the normal stresses in the X, Y, and Z directions, respectively; E is Young's modulus; and μ is Poisson's ratio.

Since $\epsilon_y=\epsilon_z=0$ at the rock surface and since $\mu=\frac{1}{2}$, equation 3 becomes

$$p_y=\frac{p_x+p_z}{2} \text{------------------} (5)$$

and equation 4 becomes

$$p_z=\frac{p_x+p_y}{2} \text{------------------} (6)$$

By substituting for p_y in equation 6 from equation 5,

$$p_z=p_x \text{------------------} (7)$$

which is true at the boundary of rock and clay.

The maximum shearing stress, $s_{\max.}$, at any point of the undersoil is

$$s_{\max.}=\left[\frac{p_z-p_x}{2}^2+s_{xz}^2\right]^{1/2} \text{----------} (8)$$

which (since $p_z=p_x$ at the rock surface) becomes

$$s_{\max.}=s_{xz} \text{------------------} (9)$$

at all points along the rock surface. Hence at the rock boundary equation 1 becomes

$$s_{\max.}=\frac{p}{2}\left[\operatorname{sech}\frac{\pi}{2}\frac{x-b}{2h}-\operatorname{sech}\frac{\pi}{2}\frac{x+b}{2h}\right] \text{------} (10)$$

which is the expression for the shearing stress at any point T of the rock surface (see fig. 1). For a triangular loading, $dp'=\frac{p}{b}dB$ (see fig. 2), where B is any variable horizontal distance from the OZ axis to the slope. By differentiating s with respect to p in equation 10 and substituting $\frac{p}{b}dB$ for dp', there is then obtained

$$ds_{\max.}=\frac{p}{2b}\left[\operatorname{sech}\frac{\pi}{2}\frac{x-B}{2h}-\operatorname{sech}\frac{\pi}{2}\frac{x+B}{2h}\right]dB \text{----} (11)$$

This is the shearing stress at T due to the shaded horizontal element of figure 2. Integration between the limits, 0 and b, yields for all such elements

$$s_{\max.}=\frac{4h}{b}\frac{p}{\pi}\Big[2\arctan e^{\frac{\pi}{2}\frac{x}{2h}}-\arctan e^{\frac{\pi}{2}\frac{x+b}{2h}}-\arctan e^{\frac{\pi}{2}\frac{x-b}{2h}}\Big] \text{-----------} (12)$$

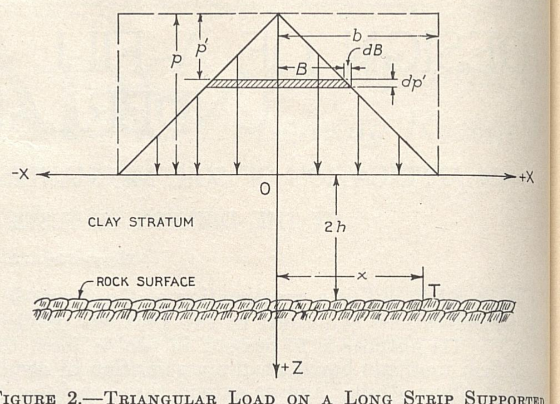

FIGURE 2.—TRIANGULAR LOAD ON A LONG STRIP SUPPORTED BY CLAY UNDERLAID BY ROCK.

This is Jürgenson's [5] formula for the shearing stress at a point T of the rock surface when the loading is triangular. (See fig. 2.) The use of equations 10 and 12 is not dependent on the relative magnitudes of h and b.

From equation 12, the greatest value of $s_{\max.}$, denoted by s_g, depends on the ratio of b to h. For example, if the depth to the rock surface, $2h$, is $\frac{1}{2}b$, then $s_{\max.}=s_g=0.318p$ at the point $x=0.625b$. If the clay has no friction, the plastic condition for these relative dimensions begins to be developed at the point $x=0.625b$ at the rock surface when

$$s_{\max.}=s_g=c=0.318p$$

or when p (see fig. 2)$=3.14c$ where c is the unit cohesion.

Similarly, for $2h=\frac{1}{4}b$, $s_{\max.}=s_g$ at $x=0.67b$ and the plastic zone begins when

$$s_{\max.}=s_g=c=0.22p$$

or when p (see fig. 2)$=4.55c$.

For any fixed ratio, $b:h$, ordinate values of $s_{\max.}$ may be plotted against x as abscissa, using equation 12. The value of x, where $s_{\max.}=s_g=$the greatest shearing stress, is the maximum ordinate of the curve thus obtained.

HENCKY'S METHOD OF PLASTIC EQUILIBRIUM IS FUNDAMENTAL

The application of the method of plastic equilibrium to this problem involving the boundary conditions illustrated in figures 1, 2, 3, 4, and 5 is limited to the condition that the distance, $2h$, must not exceed the distance, $b/2$ where $2h$ is the thickness of the clay layer and b is half the base width of the loaded surface area.

A thin layer of soil between two rigid plates whose surfaces in contact with the soil are rough and which are of great length and of width $2b$ (see fig. 3) is considered. The soil is supposed to have cohesion and a zero or very small value for its effective angle of internal friction. The method of Hencky [6] will now be shown

[5] The application of Theories of Elasticity and Plasticity to Foundation Problems, by Leo Jürgenson, Journal of the Boston Society of Civil Engineers, vol. 21, No. 3, 1934.

[6] Über Statisch bestimmte Fälle des Gleichgewichtes in plastischen Körpen, H. Hencky, Zeitschrift für ang Mathematik und Mechanik, 1924, vol. 3, p. 291, p. 401. See also Plasticity, Chapter 33, A. Nadai, 1931. McGraw-Hill Book Co.

as originally devised and applied by Prandtl[7] to the problem illustrated by figure 3, the plastic flow of soil from between two rigid plates. Certain equations for stresses will be derived in this application. Then these expressions for the stresses will be used in the solution of the problem of the fill, *ABCD*, figure 4, supported by a clay stratum underlaid by rock. First of all it is assumed (figs. 3 and 4) that h is either equal to or less than $b/4$. In no case in the following development may h be considered as greater than $b/4$. The solution follows.

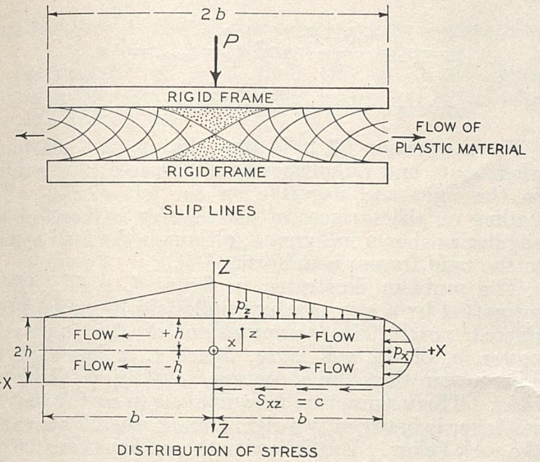

FIGURE 3.—CONDITIONS AT FAILURE IN A PLASTIC MATERIAL PRESSED BETWEEN TWO ROUGH PARALLEL PLATES.

When the material pressed between the plates by a load P (see fig. 3) becomes a plastic mass, flow occurs with a constant maximum shear expressed by the equation,

$$s_{max.}=\sqrt{\left[\frac{p_z-p_x}{2}\right]^2+s_{xz}^2}=\text{the unit cohesion } c \text{ or}$$

$$p_z-p_x=\pm 2\sqrt{c^2-s_{xz}^2} \quad \text{------}(13)$$

for according to theory, $s_{max.}$=constant=c under these conditions. There are two other equations of equilibrium, namely,

$$\frac{\partial p_x}{\partial x}+\frac{\partial s_{xz}}{\partial z}=0 \quad \text{---------------}(14)$$

and

$$\frac{\partial p_z}{\partial z}+\frac{\partial s_{xz}}{\partial x}=0 \quad \text{---------------}(15)$$

The stresses p_x, p_z, and s_{xz} may be determined from equations 13, 14, and 15. Differentiating 15 with respect to x and 14 with respect to z and subtracting, there is obtained

$$\frac{\partial^2}{\partial x \partial z}(p_z-p_x)=\frac{\partial^2 s_{xz}}{\partial z^2}-\frac{\partial^2 s_{xz}}{\partial x^2} \quad \text{----------}(16)$$

substituting equation 13 in equation 16,

$$\pm 2\frac{\partial^2}{\partial x \partial z}\sqrt{c^2-s_{xz}^2}=\frac{\partial^2 s_{xz}}{\partial z^2}-\frac{\partial^2 s_{xz}}{\partial x^2} \quad \text{--------}(17)$$

[7] L. Prandtl, Zeitschrift für ang., Mathematik und Mechanik, vol. 6, 1923.

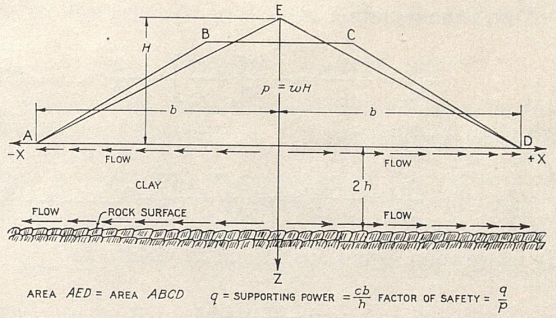

FIGURE 4.—SUPPORTING POWER OF CLAY LAYER UNDERLAID BY ROCK, METHOD OF HENCKY.

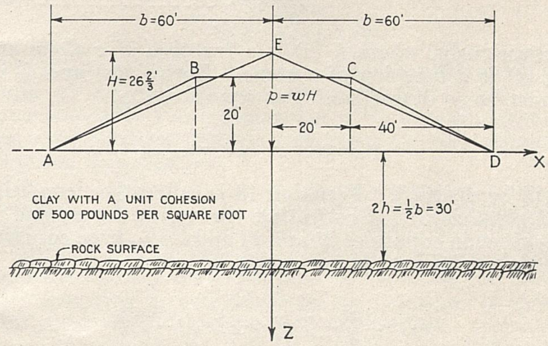

FIGURE 5.—PROBLEM OF THE SUPPORTING POWER OF A CLAY STRATUM SANDWICHED BETWEEN A FILL, *ABCD*, AND SOLID ROCK.

Equation 17 is now solved by assuming that s_{xz} depends on z alone and not on x. When this is true equation 17 reduces to

$$\frac{\partial^2 s_{xz}}{\partial z^2}=0 \quad \text{-----------------}(18)$$

which is readily integrable, and there is obtained

$$s_{xz}=K_1+K_2 z \quad \text{---------------}(19)$$

The shearing stress s_{xz} cannot anywhere exceed c, the unit cohesion. If K_1 be taken as zero, there are two straight lines (the upper and lower boundaries, fig. 3), the equations of which are $z=+h$ and $z=-h$ along which the shearing stress s_{xz} becomes $s_{max.}=c$ since by equation 9, $s_{max.}=s_{xz}$ at the rock (rigid) surface. In the present case there are two rigid surfaces, at $z=\pm h$, which form natural limits for the plastic mass. The sign of K_2 in equation 19 depends on whether $s_{xz}=+c$ or $s_{xz}=-c$ for $z=h$. If for $z=+h$, $s_{xz}=+c$, then for $K_1=0$, equation 19 becomes

$$s_{xz}=s_{max.}=+c=K_2 h$$

or

$$K_2=+\frac{c}{h}$$

and therefore for any value of z between $+h$ and $-h$,

$$s_{xz}=+\frac{cz}{h} \quad \text{----------------}(20)$$

by substitution in equation 19.

Now, from equation 14,

$$\frac{\partial p_x}{\partial x}=-\frac{\partial s_{xz}}{\partial z}=-\frac{\partial}{\partial z}\left[+\frac{cz}{h}\right]=-\frac{c}{h} \quad (21)$$

and from equation 15,

$$\frac{\partial p_z}{\partial z}=-\frac{\partial s_{xz}}{\partial x}=-\frac{\partial}{\partial x}\left[+\frac{cz}{h}\right]=0 \quad (22)$$

By integration, equations 21 and 22 yield

$$p_x=-\frac{cx}{h}+f_1(z) \quad (23)$$

and

$$p_z=f_2(x) \quad (24)$$

respectively, where f_1 (z) is a function of z alone and f_2 (x) is a function of x alone. Both f_1 (z) and f_2 (x) must be so determined that equation 13,

$$p_z-p_x=\pm 2\sqrt{c^2-s_{xz}{}^2} \quad (13)$$

will be satisfied. Equation 13 is called the "condition of plasticity." Substituting the values for p_z and p_x as given in equations 23 and 24 and for s_{xz} from equation 20 in equation 13 there results,

$$f_2(x)+\frac{cx}{h}-f_1(z)=\pm 2c\sqrt{1-z^2/h^2} \quad (25)$$

Putting $x=0$ in equation 25. Then

$$f_1(z)=K\mp 2c\sqrt{1-z^2/h^2}, \text{ where } K=f_2(0).$$

Putting $z=0$ in equation 25. Then

$$f_2(x)=K-\frac{cx}{h}, \text{ where } K=f_1(0)\pm 2c.$$

It may be easily shown that $f_1(0)\pm 2c=f_2(0)$. Hence the symbol K may denote either value.

By substitution in equations 23 and 24 there results,

$$p_x=K-\frac{cx}{h}\mp 2c\sqrt{1-z^2/h^2} \quad (26)$$

and

$$p_z=K-\frac{cx}{h} \quad (27)$$

where K is a constant.

Equations 26 and 27, together with equation 20, completely determine the stresses at any point in the plastic mass when K is known. With reference to figure 3, when $z=+h$ and $x=b$, $p_z=0$ so that by substitution in equation 27

$$0=K-\frac{cb}{h}.$$

or

$$K=+\frac{cb}{h}.$$

Therefore

$$p_x=\frac{c(b-x)}{h}\mp 2c\sqrt{1-z^2/h^2} \quad (28)$$

$$p_z=\frac{c(b-x)}{h} \quad (29)$$

and

$$s_{xz}=+\frac{cz}{h} \quad (20)$$

At the boundaries, $z=+h$ and $z=-h$,

$$p_z=p_x=\frac{c(b-x)}{h} \text{ and } s_{xz}=s_{\max.}=\pm c.$$

HENCKY'S METHOD APPLICABLE IN FILL DESIGN

From equation 29 it is seen that p_z is a maximum when $x=0$, and diminishes as x increases (b is positive on the right and negative on the left of OZ). The loading on the surfaces of plastic clay is therefore triangular as shown in figure 3, although the load applied to the rigid frames is uniform.

The problem illustrated in figure 4, a fill, $ABCD$, supported by a clay stratum underlaid by rock, is considered next. The computation of the supporting power, q, of the soil layer, figure 4, is based on the assumption that the structure, $ABCD$, is absolutely rigid. This assumption is equivalent to saying that the soil layer is between two rigid frames, the fill above and the rock below. But in order to use equations 28, 29, and 20, derived for soil between two plates, there must be made another simplifying assumption for the problem illustrated in figure 4, which is that the resistance to flow offered by the soil in the clay layer to the left of A and to the right of D (figure 4) is small enough (relatively) to be neglected.

With all these simplifying assumptions, equations 28, 29, and 20 apply in computing the supporting power, q, of the soil layer, figure 4. Since the structure, $ABCD$, is rigid, then according to equation 29 the distribution of vertical pressure, p_z, at the upper boundary (figure 4) is triangular. The same vertical stress distribution at this boundary would be realized in fact if the load diagram, $ABCD$, becomes triangular, AED, the area of $ABCD$ and that of AED being identical since the total load of the fill cross section (1 foot thick in the direction perpendicular to the plane of fig. 4) is the same.

The total vertical force, P, on a strip of unit width ($y=1$, fig. 4) on the plane boundary, $z=h$, is

$$P=2\int_0^b p_z dx=2\int_0^b \frac{c(b-x)dx}{h}$$

or

$$P=\frac{cb^2}{h} \quad (30)$$

But $P=pb$ from figure 4, where p is the maximum surface load per unit area and hence

$$P=\frac{cb^2}{h}=pb$$

or

$$p=\frac{cb}{h} \qquad (31)$$

The factor of safety against overloading of the clay stratum is q/p, q being the supporting power. At the instant of failure, $q=p=\frac{cb}{h}$.

A comparison of values obtained by the elastic theory on the one hand and the theory of plasticity on the other is now considered. It has already been shown that for $2h=\frac{1}{2}b$, the plastic zone starts to appear when the magnitude of p is such that $p=3.14c$. From equation 31 plastic flow of the entire soil mass below the fill begins when

$$q=p=\frac{cb}{h}=\frac{cb}{\frac{b}{4}}=4c$$

when

$$2h=\frac{1}{2}b \text{ or } h=\frac{b}{4}.$$

Hence for a comparison:

1. By the elastic theory, a plastic zone is started when $p=3.14\ c$.
2. By the theory of plastic equilibrium the ultimate bearing capacity q of the supporting soil is $q=4\ c$.

Thus for $2\ h=\frac{b}{2}$ the development of a plastic zone or region in the supporting soil mass begins when p is $\frac{3.14}{4}\times 100$ or 78.5 percent of the ultimate supporting power. Similarly when $2\ h=\frac{b}{4}$, the plastic zone is started when the value of p is $\frac{4.55}{8}\times 100$ or 57 percent of the ultimate bearing capacity or supporting power.

APPLICATION OF THEORY ILLUSTRATED

Suppose that it is required to know the factor of safety with respect to the supporting power of the soil below the fill, *ABCD*, figure 5, when the following conditions obtain:

1. $b=4\ h=60$ feet.
2. The fill, *ABCD*, is symmetrical with a 2 : 1 slope.
3. The height of the fill is 20 feet and the top width *BC* is 40 feet.
4. The unit weight w of fill material is 100 pounds per cubic foot.
5. The supporting soil is essentially clay. Its cohesion is 500 pounds per square foot and its angle of internal friction is too small to consider. It is then assumed that all of the supporting power is due to cohesion.

The area of the trapezoid, *ABCD*, is $\frac{BC+AD}{2}\times\text{height}=\frac{40+120}{2}\times 20=1{,}600$ square feet. The area of triangle *AED* is also 1,600 square feet and its height H is $\frac{1600}{60}=26.67$ feet. Then p is equal to $wH=100\times 26.67=2{,}667$ pounds per square foot. q is equal to $4\ c=4\times 500$ or 2,000 pounds per square foot. The factor of safety against failure of the undersoil is then

$$F=q/p=\frac{2000}{2667}=3/4.$$

Therefore the supporting soil will fail under the fill of the proposed dimensions. For the undersoil to be safe, the height H of the triangle *AED* must be reduced since $p=wH$ must be reduced. If the width of the roadway (*BC*, fig. 5) remains 40 feet and the height of the fill, *ABCD*, is reduced to 12 feet, the area of *ABCD* is then $\frac{40+120}{2}\times 12=960$ square feet and the height of the equivalent triangle is $\frac{960}{60}=16$ feet. The value p is then 1,600 pounds per square foot and

$$F=q/p=\frac{2000}{1600}=1\tfrac{1}{4}.$$

It has been shown[1] that for a cohesive soil (with no angle of internal friction) extending downward to a great depth the bearing capacity, q, for the soil supporting a symmetrical fill, as computed by two different methods, is as follows:

Method	*Value of q in terms of unit cohesion*
Terzaghi	$q=4c$ (assuming fill is nonrigid).
Prandtl	$q=5.14c$ (assuming fill is rigid).

In the foregoing example, if the rock boundary were removed and the clay extended far below it, the value of q according to Prandtl would be computed as being $5.14\times 500=2{,}570$ pounds per square foot which is larger than the value, 2,000 pounds per square foot, as found in the example. On the other hand with different relative values of b and h and the same fill as that considered in the example, the supporting power q of the clay stratum could be much greater than 2,000 pounds per square foot. Thus for h equal to $\frac{b}{8}$, $q=\frac{cb}{h}=\frac{8cb}{b}=8c=4{,}000$ pounds per square foot, a value that is much greater than that obtaining when the rock layer is nonexistent. If this condition had existed in the preceding example, the factor of safety (all other conditions being the same) would have been

$$F=\frac{q}{p}=\frac{4000}{2667}=1.5.$$

This is in accord with common sense and experience. It is obviously more difficult to "squeeze out" a thin layer of soil from between two rough steel blocks than it is to cause a much thicker layer of the same soil to flow out laterally. There is always the practical consideration that as the clay layer becomes increasingly thin, it is less a major item of cost to excavate and place the fill directly on the solid rock.

SUMMARY

Subsequent to construction a new fill tends to consolidate the supporting clay. Prior to the realization of any appreciable degree of consolidation, the fill load is carried for the most part by water in the supporting clay mass. Thus initially the superimposed fill load theoretically causes no contact pressure between solid particles and therefore no frictional force is developed by the neutral hydrostatic pressure in the supporting clay. It is during this early period following con-

[1] Principles of Soil Mechanics Involved in Fill Construction, L. A. Palmer and E. S. Barber. Proceedings Highway Research Board, Annual Meeting 1937.

struction (or possibly during construction) that failure of the supporting soil is most likely to occur. Hence it is entirely on the side of safety to consider only the cohesion in computing the supporting power.

For the case of a supporting layer of cohesive soil underlaid by rock, the author has found no expressions for shearing stresses other than those published by Carothers. Biot [8] has derived quite complicated expressions for the vertical stress p_z for the case of axially symmetric stress distribution and for the case of a line load. For $2h$=infinity his derived expressions reduce to those of Boussinesq and Mitchell. The formulas derived by Carothers do not similarly reduce, but this fact in itself indicates nothing insofar as validity is concerned.

There is no flaw in the analytical derivations of the formulas for supporting power as developed by Hencky and Prandtl and extended by Jürgenson. The limitations are inherent in the assumptions. Obviously the less rigid the fill the more untenable is the assumption of rigidity.

A solution called the "Method of Haines" has been indicated by Hough [9] for the case of a nonrigid structure.

The cases of partially rigid structures are beyond the borderline of present theoretical knowledge existing in published form and there is therefore opportunity for progress beyond this frontier.

Jürgenson [10] has recently suggested that if the fill is nonrigid, the bearing capacity, q, should be taken as $\frac{1}{2}\left(\frac{cb}{h}\right)$ which is half its value when the fill is rigid. This suggested value is only for the case when $2h$ is less than $b/2$.

The method of Haines referred to by Hough requires a more complete presentation and description than has been published to enable the student of theoretical soil mechanics to evaluate properly its utility. The fact that this method follows Jürgenson's boundary case up to $2h=0.3b$ is interesting and adds a degree of confidence in the use of Jürgenson's formula,

$$q=\frac{cb}{h}$$

for relatively thin supporting soil strata.

It is the opinion of the author that it is useless to assume a surface of failure in the supporting soil stratum in this problem. The conditions are too variable to warrant this procedure. A surface of failure is not assumed in the method of Hencky as extended and applied by Prandtl and Jürgenson. The slip lines shown in figure 3 are determinable from equations 20, 26, and 27 and are families of cycloids.

In the absence of rock, q, the supporting power, is taken with reference to the weight of a column of fill material of height equal to that of the fill and of 1 square foot cross-sectional area. For this case there are obtained by three different analytical methods the following values for q in terms of the unit cohesion c (ϕ being small enough to be neglected):

By the method of Terzaghi, $q=4c$.
By the method of Prandtl, $q=(\pi+2)c$.
By the method of Krey, $q=6c$.

These values are all for a factor of safety of one.

[8] Effect of Certain Discontinuities on the Pressure Distribution in a Loaded Soil. M. A. Biot. Publications from the Graduate School of Engineering, Harvard University, No. 172, 1935–36.

[9] Stability of Embankment Foundations, B. K. Hough, Jr. Transactions, American Society of Civil Engineers, 1938, p. 1414.

[10] On the Stability of Foundations and Embankments, Leo Jürgenson, Paper No. G–8, vol. 2, Proceedings, International Conference on Soil Mechanics and Foundation Engineering, 1936.

For the case of a rigid rock boundary below the supporting clay, the formula of Jürgenson is

$$q=\frac{cb}{h}=p$$

for a factor of safety of one, where p is the weight of a column of fill material of height equal to that of the equivalent triangle. (See fig. 3.) For $2h$ equal to or less than $b/2$, q is equal to or greater than $4c$, according to this formula. For values of $2h$ greater than $b/2$, Jürgenson's formula gives such increasingly small values for q as to be obviously in error.

The question arises as to the best procedure to follow when $2h$ is greater than $b/2$. Pending the time that a more general and satisfactory solution of this problem is obtained, the following procedures are believed to be warranted and their use is suggested.

1. For depths to rock less than one-fourth of the base width of the fill, the supporting power, q, is computed directly from Jürgenson's formula if the fill has a rigidity and strength such that it resists the shearing stress, $s_{xz}=c$, at its base.

2. For depths to rock greater than one-fourth and less than three-fourths of the base width of the fill, the value of q is considered as constant and equal to $4c$ regardless of the rigidity of the fill. In this case also q is considered as equal to p, the weight of a column of fill material of height equal to that of the equivalent triangle (*AED*, fig. 3).

3. When the depth to rock exceeds three-quarters of the base width of the fill, the analytical procedures are the same as those followed when the depth of the supporting clay is infinite. If the fill is rigid, the method of Prandtl [11] is applied. If the fill is nonrigid, the method of Terzaghi yields an appropriate value for q.

4. For an absolutely nonrigid fill and for b greater than $4h$ (fig. 2), the supporting power, q, may be computed from the formula,

$$q=\frac{1}{2}\left(\frac{cb}{h}\right).$$

In this case the ultimate supporting power of the undersoil is taken as the value of p in equation 12 when $s_{max.}$ becomes equal to c at any point x. (See fig. 2.) For depths to rock less than one-quarter of the base width of the fill, this value of p is about one-half that which is computed from the formula,

$$q=\frac{cb}{h}$$

assuming the fill is rigid.

5. All intermediate conditions, when the fill can neither resist a shearing stress, $s_{xz}=c$, nor is it nonrigid, are reserved for future study.

6. It should be possible to increase the ultimate supporting power of the undersoil by increasing the rigidity of the fill either by selection of material, methods of compacting, by special reinforcement such as the use of fascines, or by all of these means.

7. Spreading a thin blanket of gravel or sand over the undersoil and building the fill thereon would tend to hasten the process of consolidation of the soft layer of supporting soil with a consequent increase in its supporting power. The granular material in this case acts as a drainage course, providing a direct outlet for water in the voids that is under pressure transmitted by the fill load.

[11] Principles of Soil Mechanics Involved in Fill Construction, L. A. Palmer and E. S. Barber, Proceedings Highway Research Board, Annual Meeting, 1937.

SIGNIFICANT TRENDS IN MOTOR-VEHICLE REGISTRATIONS AND RECEIPTS

BY THE DIVISION OF CONTROL, PUBLIC ROADS ADMINISTRATION

Reported by ROBERT H. PADDOCK, Associate Highway Engineer-Economist

MOTOR-VEHICLE registrations in the United States in 1938 numbered 219,540 fewer than in the preceding year. This amounted to a decline of 0.7 percent from 1937 registrations and marked the fourth time in the history of the automotive industry that the total registrations for one year were less than those for the preceding year.

The history of motor-vehicle registrations in this country has generally been one of continual growth; an increase each year over the preceding one has come to be expected. The course of registrations since 1914 is shown graphically in figure 1. The decreases in 1931, 1932, and 1933 resulted from the economic depression which started in 1929, and the recession of 1937 undoubtedly accounts for most of the registration decrease in 1938 from 1937. It will be interesting in succeeding years to observe the registration trends and to compare motor-vehicle registrations of the next decade with those of the nine-year period ending with 1938.

Passenger-car and bus registrations of 25,261,649 and truck registrations of 4,224,031 made up the reported 1938 total of 29,485,680 vehicles. It should be noted that in spite of marked improvements in registration practice in all States during the past decade, the available data are not entirely comparable among States. Passenger-car registrations in some States include vehicles that elsewhere would be registered as trucks. Busses are registered with passenger cars in some States, and with trucks in other States, and in many cases are not readily separable. However, it is believed that these inconsistencies in registration practice are not great enough in total to affect the general observations and conclusions which can be drawn from the available data.

The percentage of decrease recorded in 1938 for passenger-car registrations was slightly greater than that for trucks. This condition was also characteristic of motor-vehicle registrations in the early part of the decade. In 1930 an increase in truck registrations more than compensated for a decrease in passenger-car registrations, causing a slight net increase in total motor-vehicle registrations for that year over 1929.

PERCENTAGE INCREASE IN TRUCK REGISTRATIONS EXCEEDS THAT FOR PASSENGER CARS

Table 1 shows the respective annual changes and the differences in the annual rates of change during the past 18 years in passenger-car and truck registrations. Since 1921 truck registrations have increased faster or have decreased more slowly as compared with the preceding year's registrations for every year but 2 than have the corresponding passenger-car registrations. These 2 years were 1923 and 1932. In the former year, the greatest single year's percentage increase in passenger-car registrations since 1920 occurred. This was an increase of 23.8 percent while truck registrations recorded an increase of 19.2 percent. This lag in truck registration growth was more than compensated for by the 1924 registrations when passenger cars recorded a substantial increase of 14.7 percent while truck registrations were 32.8 percent higher than those of the preceding year.

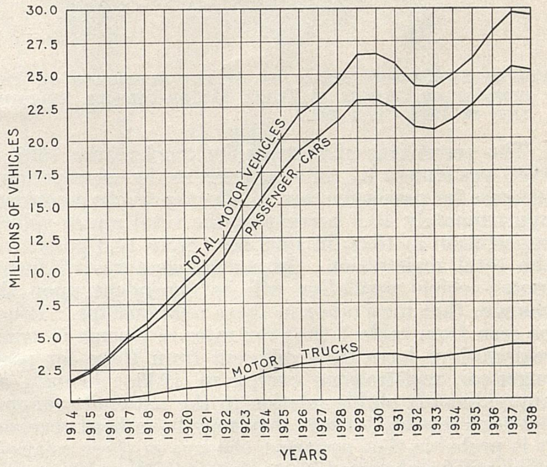

FIGURE 1.—MOTOR-VEHICLE REGISTRATIONS IN THE UNITED STATES, 1914–38.

Again, in 1932, the drop in truck registrations was 6.8 percent compared to 6.5 percent for passenger cars. But in 1931 passenger car registrations had dropped 3.1 percent in contrast to a 0.6 percent drop for trucks and in 1933 passenger-car registrations showed a drop of 1.2 percent compared to a very small increase for trucks.

TABLE 1.—*Comparison of variation in registration of passenger cars and trucks, 1921 to 1938* [1]

Year	Increase or decrease in registration from previous year				Increase in registration over 1921			
	Passenger cars		Trucks		Passenger cars		Trucks	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
1922	1,523,170	16.3	251,910	23.0	1,523,170	16.3	251,910	23.0
1923	2,594,226	23.8	258,335	19.2	4,117,396	44.0	510,245	46.5
1924	1,976,282	14.7	526,459	32.8	6,093,678	65.1	1,036,704	94.6
1925	2,035,771	13.2	307,826	14.4	8,129,449	86.8	1,344,530	122.6
1926	1,740,751	9.9	323,368	13.2	9,870,200	105.4	1,667,898	152.1
1927	982,052	5.1	149,796	5.4	10,852,252	115.9	1,817,694	165.8
1928	1,159,902	5.7	199,981	6.9	12,012,154	128.2	2,017,675	184.0
1929	1,742,464	8.2	265,855	8.5	13,754,618	146.8	2,283,530	208.3
1930	−62,327	−.3	106,165	3.1	13,692,291	146.2	2,389,695	218.0
1931	−711,239	−3.1	−19,939	−.6	12,981,052	138.6	2,369,756	216.2
1932	−1,462,209	−6.5	−236,765	−6.8	11,518,843	123.0	2,132,991	194.6
1933	−242,250	−1.2	1,353	(2)	11,276,593	120.4	2,134,344	194.7
1934	888,844	4.3	188,586	5.8	12,165,437	129.9	2,322,930	211.9
1935	1,051,012	4.9	228,160	6.7	13,216,449	141.1	2,551,090	232.7
1936	1,594,791	7.1	339,925	9.3	14,811,240	158.1	2,891,015	263.7
1937	1,271,713	5.3	267,957	6.7	16,082,953	171.7	3,158,972	288.1
1938	−188,275	−.7	−31,265	−.7	15,894,678	169.7	3,127,707	285.3

[1] Busses included with passenger cars. [2] Less than 0.1 percent.

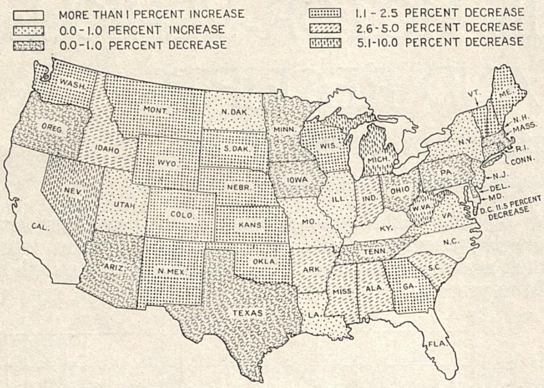

FIGURE 2.—CLASSIFICATION OF STATES ACCORDING TO PERCENTAGE OF CHANGE IN TOTAL MOTOR-VEHICLE REGISTRATION IN 1938 OVER 1937.

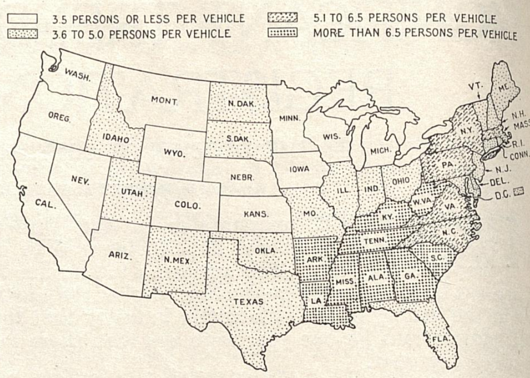

FIGURE 3.—CLASSIFICATION OF STATES ACCORDING TO NUMBER OF PERSONS PER REGISTERED VEHICLE IN 1938.

The percentage of increase for trucks from 1922 to 1938 was almost 1.7 times as great as the corresponding increase for passenger cars. Whereas trucks comprised approximately 10.5 percent of the total motor-vehicle registration in 1921, in 1938 they were 14.3 percent of the total registration. Important features of future motor-vehicle regulation will be dependent upon the changes that may occur in those relationships. It can be seen from table 1 that the rates of change in truck registrations have been different from those for passenger-car registrations except in 1938. Though an approximately stable relation in the national economy between cars and trucks may now have been reached, it is probable that apparent changes in these relationships will be observed in the future without the occurrence of any real changes. Such apparent though not real changes may occur if more nearly correct classification and registration practices are adopted by those States where passenger-car registrations, for example, now contain a considerable number of vehicles that should properly be designated as trucks.

The Administration's statistical tables, State Motor-Vehicle Registrations and Receipts, 1938, appearing in the June 1939, issue of PUBLIC ROADS showed that 33 States [1] reported decreases in total 1938 registrations from their respective 1937 registrations. The greatest numerical decrease was in Michigan with a reported decrease of 96,276 vehicles, which accounted for 29 percent of the change in the 33 States reporting such losses. The Michigan condition was exaggerated by reflection of the conditions in the automobile market in the rest of the country.

The large decrease in the District of Columbia registration, where the largest percentage decrease was recorded, is believed to have been occasioned largely by the revision in registration fees in 1938 when the previous $1 fee was abandoned for higher rates. This change undoubtedly caused the retirement of some vehicles that might have been registered at the lower rate. The change also probably resulted in the proper registration of vehicles from other States in their own States where formerly they had escaped the higher rates in their own States by registering in the District of Columbia or had been registered both in their own States and in the District of Columbia.

Large decreases were also reported in Indiana, West Virginia, and Wisconsin. Other States showing decreases of more than 10,000 vehicles were Alabama, Kansas, Mississippi, Oklahoma, and Washington. Only four States—California, Illinois, New York and North Carolina—reported increases of more than 10,000 in their registrations.

The percentage changes by States in total vehicle registrations are shown in figure 2. It is significant that there is no uniform pattern among the States except in the Rocky Mountain area. States showing increases are scattered throughout the country.

SUBSTANTIAL DECLINE NOTED IN PERSONS PER REGISTERED VEHICLE

The characteristics noted for all motor vehicles were generally true for passenger cars and trucks separately, though only 28 States showed decreases in truck registrations. Arizona, Iowa, Kansas, Massachusetts, Montana, Nebraska, New Hampshire, Ohio, Tennessee, Texas, West Virginia, and Wyoming all reported increases in truck registrations though the total number of vehicles registered in each of those States decreased. However, in Florida, Louisiana, Missouri, New Jersey, New York, Utah, and Virginia where there were net increases in total motor vehicles registered there were actual decreases in the number of trucks registered.

These differences among the States suggest that with the exception of Michigan and the District of Columbia, which apparently reflect certain peculiar conditions, the causes of the changes in registration in other States must be sought in a variety of governmental, economic, and social factors. For example, the decreases in total registrations in some States, accompanied by increases in truck registrations, may actually be caused by changes in local registration practices rather than by changes in the classes of vehicles in operation. Again, decreases in car registrations as contrasted to increases in truck registrations in such States as Kansas, Nebraska, and Texas may be caused by farmers who, for reasons of economy, refrain from registering automobiles still owned, and use their trucks for both business and pleasure driving.

Since it is impossible to draw sound general conclusions from the data for a single year or even for a few years, it is desirable to identify certain basic State and national trends in motor-vehicle ownership. One approach to this is a determination of the distribution, by States, of motor vehicles among the entire population. These data are presented in figure 3 which shows graphically the number of persons per registered motor

[1] The District of Columbia is classed as a State in this report.

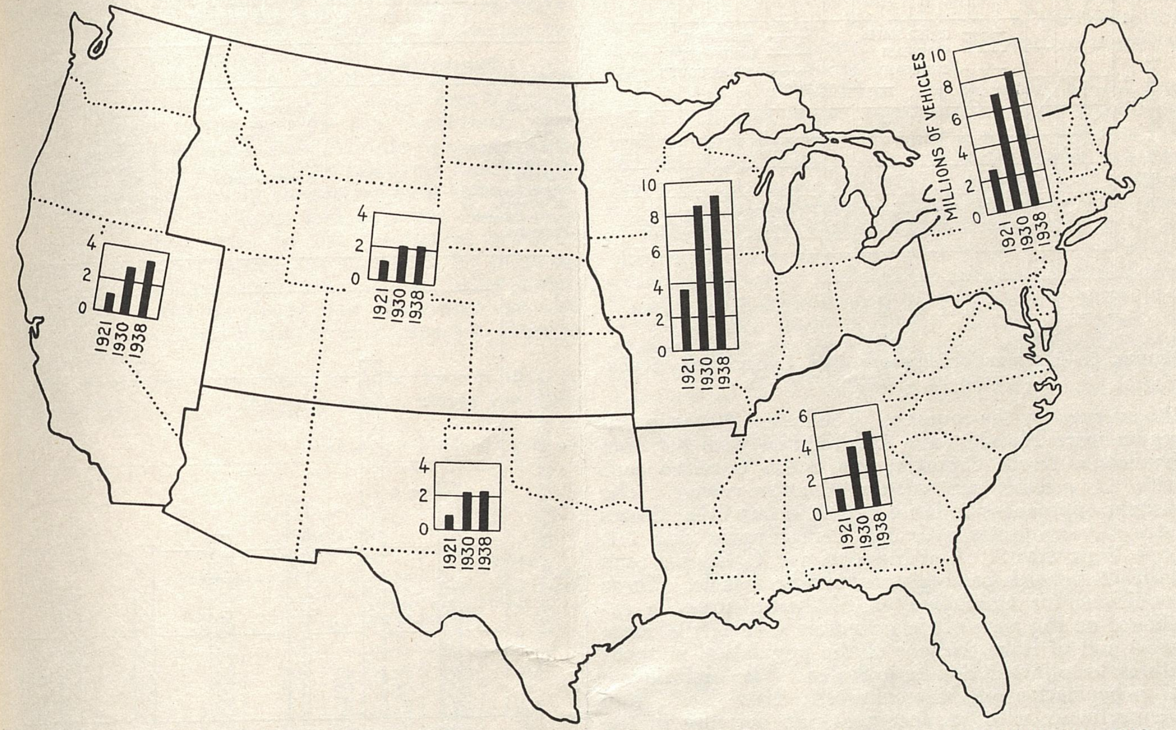

FIGURE 4.—TOTAL MOTOR-VEHICLE REGISTRATIONS, IN MILLIONS OF VEHICLES, BY REGIONS IN 1921, 1930, AND 1938.

vehicle in the several States in 1938. This figure indicates certain quite definite patterns of motor-vehicle ownership throughout the country with relatively the fewest vehicles in the Southeast and the most in the Far West.

In order to study these characteristics in greater detail and to determine what regional characteristics there may be the country was divided into six areas. These differ somewhat from the geographical areas used by the United States Bureau of the Census since adherence to those areas would not bring out clearly the significant differences throughout the country. The areas are similar to those selected by the National Resources Committee in their report Problems of a Changing Population. One change from the grouping used in that study has been made—West Virginia has been grouped with the Southeastern States instead of with those of the Northeast.

The States included in the several areas are shown in figure 4 which also gives the number of motor-vehicle registrations in the several areas in 1921, 1930, and 1938. This graph indicates the greater proportional registration growth in the Southeastern States between 1921 and 1938, and particularly between 1921 and 1930, in comparison with the increases in other areas. Table 2 shows this growth strikingly also by expressing the data as persons per registered vehicle at the beginning, middle, and end of the period studied. Thus, while the change in the Southeast constituted a 63-percent decrease from 1921 to 1930 in the number of persons per vehicle, the corresponding decrease in the Northwest was only 48 percent, and in the Far West 50 percent.

The year-by-year change in persons per vehicle in the several regions is shown in figure 5 which illustrates the rapid drop for all areas until 1929, followed by the rise during the depression years and the subsequent drop again for all regions since 1933. The computations for this figure are based on the annual midyear population estimates, by States, made by the United States Bureau of the Census. Computations for 1938 are based on the latest available population estimates—those for 1937.

TABLE 2.—*Persons per registered motor vehicle, by regions*

Region	Persons per motor vehicle in—		
	1921	1930	1938
Northeast	12.1	5.2	4.8
Southeast	20.1	7.4	6.9
Southwest	10.2	4.3	4.1
Middle States	8.1	3.9	3.8
Northwest	6.6	3.4	3.4
Far West	6.0	3.0	2.6
United States	10.4	4.6	4.4

SOUTHEAST REGION HAS GREATEST NUMBER OF PERSONS PER VEHICLE

It is evident that though since 1921 there has been a relatively greater increase in the number of vehicles in relation to the population in the Southeast than in any other region, it still is considerably higher than the country as a whole in persons per vehicle. Judged by this criterion alone, the Southeast may be thought of as the region where potentially the greatest percentage increase in vehicles may occur in the future.

It is significant that all of the 11 States having over 6 persons per vehicle were in the Southeast region. In Florida, the only other State in this region, the number of persons per vehicle in 1938 was lower than

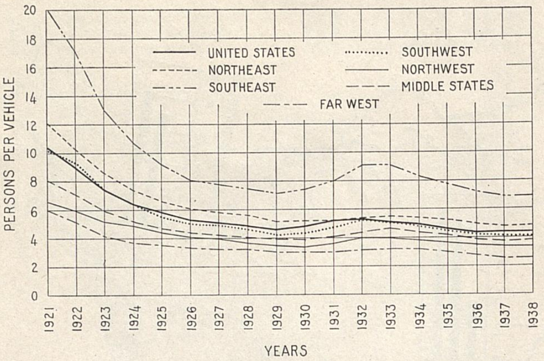

FIGURE 5.—NUMBER OF PERSONS PER REGISTERED MOTOR-VEHICLE BY REGIONS, 1921–38.

the average for the country. The lowest States in this region were Florida with 3.9, Virginia with 6.1, and Louisiana, North Carolina, and South Carolina each with 6.5 persons per registered motor vehicle. The nearest approaches to these figures in any other States were Massachusetts with 5.2, Pennsylvania with 5.1, New York with 5.0, and Missouri and Oklahoma each with 4.8 persons per registered motor vehicle. These conditions for Oklahoma and Missouri may be explained on the basis of the economic similarity of large areas and of large sections of the population in those States to adjacent Southern States. The high degree of urbanization of Massachusetts, New York, and Pennsylvania with an accompanying decrease in the economic utility of a car for large portions of the population and the presence of large economically depressed coal-mining regions in Pennsylvania provide at least partial explanations of the figures for those States.

Comparison of the State motor-vehicle-registration data for the years 1929, 1930, and 1931 reveals that the peaks of registration during that period were reached at different times in different States. With the exceptions of Montana, North Dakota, and Oklahoma, no western State reached its peak in 1929. On the other hand, of the 10 States which had their greatest registration for the period in 1931, 4 were in the West.

In a study of trends in motor-vehicle registration, however, it is more significant that in 11 States registrations in 1938 were less than in the peak year of the 1929–31 period and that of these, only Massachusetts and the District of Columbia have had in at least 1 year since 1931 a total registration which exceeded the peak year of the 1929–31 period. Table 3 shows the States where such conditions existed for passenger cars, for trucks, and for all motor vehicles. Though the increases in car ownership since 1934 have been considerable it is significant that in almost one-fifth of the States, representing 10.6 percent of the registrations in 1938, motor-vehicle registrations had not yet regained the peak reached during the 1929–31 period.

Whether recovery in registrations is only delayed in those nine States, or whether the 1929–31 peak will remain an all-time high or will remain unequaled for several years in at least some of those States is dependent on many national economic and demographic factors. Six of the nine States recorded their greatest registrations since the 1929–31 period in 1937, but the post-depression high was reached in Nebraska and South Dakota in 1936 while the registration in North Dakota was greater in 1938 than in 1937.

TABLE 3.—*States in which registrations since 1929–31 have not reached those of the peak year of that period*

Passenger cars	Trucks	All motor vehicles
Arkansas. Iowa. Kansas. Massachusetts. Mississippi. Nebraska. North Dakota. Oklahoma. South Dakota. Vermont.	Delaware. Michigan. New Jersey. New York. Ohio. Rhode Island.	Arkansas. Iowa. Kansas. Mississippi. Nebraska. North Dakota. Oklahoma. South Dakota. Vermont.

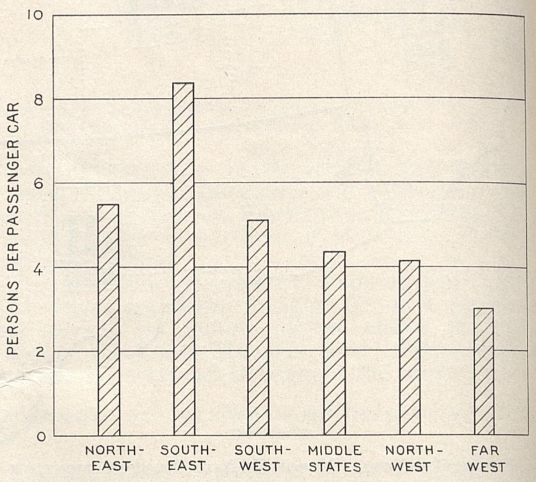

FIGURE 6.—NUMBER OF PERSONS PER REGISTERED PASSENGER CAR BY REGIONS, IN 1938.

SOUTHWEST REGION HAS SMALLEST RATIO OF PASSENGER CARS TO TRUCKS

Some further indication of regional characteristics may be brought out by a comparison of the ratio of passenger-car to truck registrations in the several regions. Table 4 shows the results of that analysis by regions for 1921, 1930, and 1938. The comparison in table 2 of persons per registered motor vehicle only does not present a complete picture of vehicle ownership characteristics by regions. One reason for this is that the relative ownership and use of trucks varies considerably in different parts of the country, particularly among the agricultural population. In some areas trucks serve both for the usual hauling purposes and also for transportation of persons. In other areas, the use of trucks is restricted more to the hauling function. Figure 6 shows for 1938 the persons per registered passenger car in the several regions. This chart indicates a general similarity between passenger-car and total motor-ve-

TABLE 4.—*Ratio of passenger cars to trucks by regions*

Region	Registration years		
	1921	1930	1938
Northeast	6.5	6.2	6.6
Southeast	7.8	6.4	4.8
Southwest	12.5	6.2	4.0
Middle States	8.7	7.0	7.1
Northwest	12.1	6.3	4.7
Far West	11.8	7.7	6.6
United States	8.5	6.6	6.0

hicle registrations by regions, with the Southeast showing the highest number of persons per passenger car and the Far West the lowest number.

Table 4 shows, however, that there is a considerable difference between the ratio of passenger cars to trucks in the Middle States and in the Southwest. The observed characteristic of the Middle States is probably due in large part to the relatively high ownership of passenger cars in connection with the automotive industry in Michigan and adjacent States. In contrast, the low ratio in the Southwest probably indicates the more general use of trucks for purposes for which passenger cars are used in other areas. Conditions in the Southeast and Northwest are also apparently somewhat similar in this respect to those in the Southwest.

It is particularly surprising to note the condition in the Northeast. It is the only region where the ratio of passenger cars to trucks was higher in 1938 than in both 1930 and 1921. No explanation of this condition is immediately apparent though registration practices may have had considerable effect.

In addition to the 29,485,680 privately owned passenger cars and trucks registered in 1938, there were also in operation 109,761 Federal motor vehicles and 257,469 State, county, and municipal motor vehicles. These figures, shown in table 5, represent a 4.7 percent increase in Federal vehicles and an 11.3 percent increase in other publicly owned vehicles in 1938 over 1937. This tabulation also illustrates strikingly the inadequacies of present registration practice in the several States. In some instances publicly owned vehicles are included with those privately owned; in others no record is kept of such vehicles at all; and in still others there is no segregation between Federal vehicles and those owned by the States, counties and municipalities.

TABLE 5.—*Publicly owned vehicles in the United States in 1938* [1]

State	Federal [2]								State, county, and municipal [3]								
	Motor vehicles					Trailers and semi-trailers	Motor-cycles	Total vehicles	Motor vehicles						Trailers and semi-trailers	Motor-cycles	Total vehicles
	Passenger motor vehicles			Motor trucks, tractor trucks, etc.	Total motor vehicles				Passenger motor vehicles			Motor trucks, tractor trucks, etc.	Type not reported	Total motor vehicles			
	Auto-mobiles	Motor busses	Total						Auto-mobiles	Motor busses	Total						
Alabama	440	13	453	1,539	1,992	55	4	2,051					3,755	3,755		143	3,898
Arizona	496	73	569	1,805	2,374	97	4	2,475	527	207	734	1,320		2,054	181	23	2,258
Arkansas	270	8	278	1,789	2,067	25	1	2,093	1,264	1,042	2,306	887		3,193	13	31	3,237
California	1,121	71	1,192	6,347	7,539	276	75	7,890					24,502	24,502	1,646	1,157	27,305
Colorado	367	23	390	1,957	2,347	23	7	2,377									(4)
Connecticut	64	1	65	590	655	6	1	662	1,450		1,450	2,441		3,891	87	294	4,272
Delaware	15		15	297	312	4		316					896	896	25	62	983
Florida	349	10	359	1,428	1,787	25	15	1,827	1,130	707	1,837	3,235		5,072	317	168	5,557
Georgia	582	39	621	2,044	2,665	45	33	2,743	1,033		1,033	2,986		4,019	63	138	4,220
Idaho	134	3	137	1,404	1,541	80		1,621	341	144	485	1,063		1,548	89	11	1,648
Illinois	507	9	516	2,801	3,317	98	19	3,434	2,573		2,573	6,919		9,492	323	654	10,469
Indiana	193	1	194	1,437	1,631	86	15	1,732	1,784		1,784	4,385		6,169		195	[5] 6,364
Iowa	187	1	188	1,224	1,412	22	6	1,440	1,309		1,309	4,745		6,054	357	66	[5] 6,477
Kansas	230	2	232	1,272	1,504	61	9	1,574									(4)
Kentucky	277	3	280	1,291	1,571	11	109	1,691	1,011		1,011	3,314		4,325			[5] 4,325
Louisiana	413	16	429	1,398	1,827	27	13	1,867	1,971	32	2,003	2,722		4,725	380	63	[5] 5,168
Maine	119	1	120	432	552	10	5	567	630	87	717	1,370		2,087	164	31	2,282
Maryland	379	21	400	1,966	2,366	61	21	2,448									(4)
Massachusetts	428	20	448	2,269	2,717	31	11	2,759					5,700	5,700			5,700
Michigan	304	5	309	2,233	2,542	81	17	2,640									(4)
Minnesota	395	3	398	2,111	2,509	56	10	2,575					4,790	4,790			4,790
Mississippi	174	18	192	1,283	1,475	57	1	1,533									(4)
Missouri	317	15	332	1,753	2,085	27	6	2,118	571		571	1,606		2,177		9	2,186
Montana	389	3	392	1,698	2,090	27		2,117					2,201	2,201			[5] 2,201
Nebraska	243	3	246	953	1,199	14	8	1,221	539	52	591	1,871		2,462		46	2,508
Nevada	141	5	146	550	696	21	2	719	147	25	172	467		639	48	8	695
New Hampshire	21		21	634	655	19	1	675									(4)
New Jersey	266	5	271	2,492	2,763	26	14	2,803	4,180		4,180	6,297		10,477		545	11,022
New Mexico	457	12	469	1,709	2,178	67		2,245	571		571	340		911		41	952
New York	919	36	955	4,674	5,629	49	81	5,759	6,462	1,577	8,039	18,044		26,083	881	1,036	[5] 28,000
North Carolina	380	13	393	1,788	2,181	42	3	2,226		4,850	4,850		6,821	11,671			11,671
North Dakota	154	19	173	615	788	12		800					699	699			699
Ohio	390	10	400	2,076	2,476	85	6	2,567	3,234	7,125	10,359	8,409		18,768	1,125	576	20,469
Oklahoma	507	20	527	1,908	2,435	42	14	2,491					6,719	6,719			6,719
Oregon	337	8	345	2,476	2,821	33	4	2,858	1,672		1,672	2,399		4,071			4,071
Pennsylvania	482	5	487	3,496	3,983	123	24	4,130	5,601	138	5,739	12,061		17,800	463	1,226	19,489
Rhode Island	43	12	55	405	460	16	1	477	492		492	917		1,409	23	105	1,537
South Carolina	245	17	262	1,308	1,570	14	5	1,589					4,468	4,468		146	4,614
South Dakota	208	13	221	1,020	1,241	17	2	1,260	227	122	349	783		1,132	152	12	1,296
Tennessee	369		369	1,799	2,168	45	2	2,215					7,105	7,105			7,105
Texas	1,193	33	1,226	4,142	5,368	148	75	5,591	2,350	3,989	6,339	9,566		15,905	1,193	378	17,476
Utah	265	3	268	1,490	1,758	56	10	1,824	332	228	560	818		1,378	64	46	1,488
Vermont	126	2	128	520	648	14		662									(4)
Virginia	408	42	450	2,781	3,231	217	52	3,500	2,685		2,685	2,785		5,470	165	183	[5] 5,818
Washington	603	5	608	2,607	3,215	77	27	3,319	1,644	1,621	3,265	3,685		6,950	336	164	7,450
West Virginia	148	2	150	1,038	1,188	6		1,194	1,760		1,760	3,349		5,109	148	70	5,327
Wisconsin	267	3	270	2,030	2,300	39	5	2,344	1,232	344	1,576	6,970		8,546	204	360	9,110
Wyoming	205	4	209	1,091	1,300	26	9	1,335	297		297	384		681	57		738
District of Columbia	354	7	361	901	1,262	20	62	1,344	[6] 1,265		1,265	1,101		2,366	106	94	2,566
At large [7]	1,090	9	1,099	4,272	5,371	45	10	5,426									
Total	17,971	647	18,618	91,143	109,761	2,564	799	113,124	50,284	22,290	72,574	117,239	67,656	257,469	8,610	8,081	274,160

[1] Because the 2 parts of this table were obtained from different sources, and the State, county, and municipal figures contain some duplication of Federal vehicles, totals of all publicly owned vehicles are not given. Data given in this table are included in condensed form in table State Motor-Vehicle Registrations, 1938.

[2] This information was obtained by the Procurement Division, Department of the Treasury, by means of a circular letter addressed to all departments and independent offices.

[3] This information, compiled from reports of State authorities, is incomplete in many cases. Some States give State-owned vehicles only; others exclude from registration certain classes, such as fire apparatus and police vehicles.

[4] Not reported. Included with private and commercial registrations in table State Motor-Vehicle Registrations, 1938.

[5] Includes unknown number of Federal vehicles.

[6] Includes 405 automobiles of the diplomatic corps.

[7] Includes 2,314 War Department vehicles operated in military reservations, arsenals, etc., but not distributed to State of domicile.

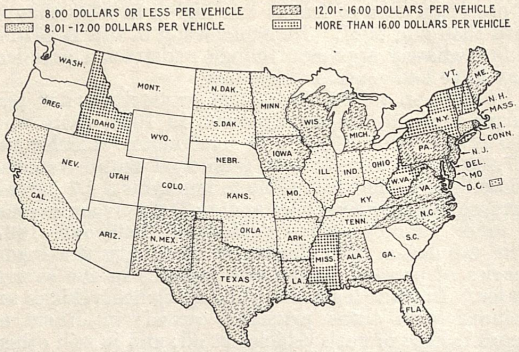

Figure 7.—Classification of States According to Average Motor-Vehicle Registration Fees in 1938.

Consequently, the data of table 5 serve only as an indication of the extent of public vehicle ownership and should not be considered a definitive tabulation of publicly owned vehicles in the United States in 1938.

STATES RANKED ACCORDING TO REGISTRATIONS AND FEES PAID

The Administration's statistical table State Motor-vehicle Receipts, 1938, published in the June 1939, issue of Public Roads, revealed a slight decrease in total collections from those reported for 1937. Receipts of registration fees rose from $328,285,000 in 1937 to $330,866,000 in 1938, an increase of 0.8 percent; but reductions in other receipts, including those from operators' and chauffeurs' permits, certificates of title, and transfer or reregistration fees, caused the total receipts to fall from $399,613,000 in 1937 to $388,825,000 in 1938, a decrease of 2.7 percent.

While it has been observed that there are rather general regional patterns of motor-vehicle ownership in the several States, such patterns are not so marked in the case of motor-vehicle receipts. Figure 7 shows the grouping of States by various average registration fees paid and indicates that a general pattern comparable with that of figure 3 is not apparent. In general, the lowest average fees are charged in the Western States but the Eastern and Southern States of Georgia, Kentucky, Massachusetts, and South Carolina are in the lowest group and Georgia collects the lowest average fee of any State. These data are presented in more detail in table 6 for passenger cars and trucks as well as for all motor vehicles. It will be seen that average passenger-car fees range from $2.74 in Georgia to $18.12 in Vermont, that average truck fees range from $6.56 in Georgia to $63.48 in Vermont and that average fees for all motor vehicles range from $3.39 to $22.81 in the same States.

The figures for Vermont are not truly representative because the lighter trucks are included in the passenger-car registrations, thus raising the average of those fees in comparison with other States. This illustrates another of the weaknesses of existing registration data when comparisons such as these are desired.

Table 7 shows the ranking of the States in 1938 in registrations, in gross receipts from motor-vehicle license fees, in average motor-vehicle receipts per vehicle, revenue from the motor-fuel tax, average motor-fuel tax receipts per vehicle, and average motor-vehicle and motor-fuel tax receipts per vehicle. It will be observed that there is apparently little correlation between the ranking of the States according to number of vehicles registered and according to motor-vehicle registration receipts. This is to be expected, of course, because of the wide disparity in registration fees charged in the several States.

Table 6.—*Average registration fees per vehicle in 1938*

State	Passenger vehicles [1]	Motor trucks	Average for all motor vehicles
Alabama	----	----	$12.78
Arizona	$3.76	$17.87	6.28
Arkansas	9.43	17.24	11.32
California	7.68	13.61	8.38
Colorado	5.65	8.70	6.16
Connecticut	7.63	20.20	9.65
Delaware	11.33	27.28	13.95
Florida	11.46	25.28	13.75
Georgia	2.74	6.56	3.39
Idaho	14.93	22.43	16.46
Illinois	8.95	27.37	11.19
Indiana	7.43	13.27	8.23
Iowa	12.94	30.99	15.12
Kansas	5.34	9.44	6.03
Kentucky	4.98	19.25	7.17
Louisiana	11.80	16.51	12.92
Maine	12.32	19.38	13.85
Maryland	8.72	11.20	9.06
Massachusetts	3.71	13.22	4.88
Michigan	9.93	37.37	12.64
Minnesota	9.77	16.75	10.75
Mississippi	----	----	18.34
Missouri	9.86	10.00	9.88
Montana	6.54	7.70	6.82
Nebraska	3.63	13.73	5.24
Nevada	5.02	11.96	6.38
New Hampshire	----	----	18.19
New Jersey	11.28	30.33	13.80
New Mexico	10.66	20.41	12.91
New York	14.02	36.17	16.80
North Carolina	8.92	36.24	12.79
North Dakota	7.60	10.01	8.06
Ohio	8.66	42.24	11.96
Oklahoma	5.99	18.66	8.22
Oregon	5.12	17.97	7.27
Pennsylvania	11.06	34.88	14.02
Rhode Island	11.57	25.19	13.13
South Carolina	2.97	14.13	4.57
South Dakota	8.93	7.86	8.76
Tennessee	----	----	9.80
Texas	9.76	21.14	12.09
Utah	4.76	20.58	7.25
Vermont	18.12	63.48	22.81
Virginia	10.94	20.08	12.34
Washington	3.16	13.20	4.75
West Virginia	15.08	23.22	16.41
Wisconsin	13.32	22.00	14.73
Wyoming	5.70	10.92	6.83
District of Columbia	----	----	8.18
Average for United States	[2] 9.25	[2] 22.66	11.22

[1] Includes automobiles and busses. In some States busses are registered with motor trucks. In Alabama, Mississippi, New Hampshire, Tennessee, and the District of Columbia, no classification of registration fees by types was available.
[2] Excluding those States for which no segregation of fees was available.

It will be noted that the average receipts from motor-fuel taxes vary much less than do receipts from motor-vehicle registration fees. The maximum is the $54.92 average for Florida where the State tax is 7 cents per gallon and a large amount of gasoline is used by non-residents. The latter fact, particularly, causes certain of the State figures—based on registrations—to be inflated when compared with data for other States. The lowest collections per vehicle were in Missouri, North Dakota, and the District of Columbia. The first and last of these can be explained by the 2-cent gas tax in effect, while in North Dakota the refund procedure followed acts to reduce the average tax collected per vehicle. California, Iowa, Kansas, and Michigan, all with motor-fuel tax rates of 3 cents per gallon, also received less than $20 in motor-fuel taxes per vehicle. The remaining five States with 3-cent tax rates all collected less than $24 per vehicle in motor-fuel taxes and of these, only two—Massachusetts and New Jersey—collected more than $21 per vehicle from such taxes.

Table 7.—*Total motor vehicles registered, State registration fees, motor-fuel taxes paid, and averages per vehicle, in 1938* [1]

State	Number of registered private and commercial passenger cars, busses, and trucks	Rank of State	Total receipts from State motor-vehicle registration and other fees	Rank of State	Average State motor-vehicle receipts per vehicle	Rank of State	Revenue from State motor-fuel tax	Rank of State	Average State motor-fuel tax receipts per vehicle	Rank of State	Average State motor-vehicle and motor-fuel tax receipts per vehicle	Rank of State
			1,000 dollars				*1,000 dollars*					
Alabama	301,990	30	4,314	24	$14.28	19	13,579	21	$44.97	8	$59.25	4
Arizona	128,791	41	1,076	46	8.35	38	4,243	37	32.94	13	41.29	22
Arkansas	220,391	33	2,908	31	13.19	23	10,092	29	45.79	5	58.98	5
California	2,510,867	2	23,930	4	9.53	34	47,117	3	18.77	44	28.30	45
Colorado	332,774	28	2,544	34	7.64	41	7,465	34	22.43	38	30.07	44
Connecticut	440,335	20	6,611	16	15.01	15	9,242	33	20.99	40	36.00	32
Delaware	64,078	47	1,216	44	18.98	5	2,073	47	32.35	14	51.33	11
Florida	423,021	22	6,432	17	15.20	14	23,232	9	54.92	1	70.12	1
Georgia	432,360	21	1,974	39	4.56	48	19,633	13	45.41	6	49.97	12
Idaho	137,851	40	2,380	36	17.27	10	4,085	40	29.63	18	46.90	15
Illinois	1,780,865	5	21,591	5	12.12	26	36,888	6	20.71	41	32.83	42
Indiana	922,788	9	9,635	11	10.44	33	22,770	10	24.68	32	35.12	36
Iowa	740,021	14	11,797	10	15.94	12	13,234	22	17.88	45	33.82	39
Kansas	573,985	15	3,823	27	6.66	44	10,168	28	17.71	46	24.37	47
Kentucky	414,207	23	4,599	23	11.10	29	12,531	23	30.25	17	41.35	21
Louisiana	326,199	29	4,892	22	15.00	16	16,627	17	50.97	2	65.97	2
Maine	196,690	35	3,582	28	18.21	8	5,558	35	28.26	21	46.47	16
Maryland	395,347	26	5,069	21	12.82	25	9,929	30	25.11	31	37.93	28
Massachusetts	843,789	10	6,759	15	8.01	40	20,194	12	23.93	34	31.94	43
Michigan	1,408,835	7	20,856	6	14.80	17	27,683	7	19.65	43	34.45	38
Minnesota	821,241	13	9,377	13	11.42	27	19,570	14	23.83	35	35.25	35
Mississippi	215,195	34	4,001	26	18.59	6	10,181	27	47.31	4	65.90	3
Missouri	837,118	12	9,439	12	11.28	28	11,636	24	13.90	47	25.18	46
Montana	171,326	38	1,546	42	9.02	35	4,452	36	25.99	28	35.01	37
Nebraska	407,330	24	2,442	35	5.99	46	11,139	26	27.35	25	33.34	41
Nevada	38,424	48	265	48	6.90	43	1,202	48	31.28	15	38.18	26
New Hampshire	124,379	43	2,711	33	21.80	2	3,298	43	26.51	26	48.31	14
New Jersey	1,000,684	8	20,204	8	20.19	3	22,362	11	22.35	39	42.54	20
New Mexico	116,537	44	1,643	40	14.10	20	4,090	39	35.09	11	49.19	13
New York	2,584,123	1	47,124	1	18.23	7	66,195	1	25.62	30	43.85	18
North Carolina	537,242	16	7,211	14	13.42	22	24,308	8	45.25	7	58.67	7
North Dakota	174,256	37	1,523	43	8.74	36	2,318	46	13.30	48	22.04	48
Ohio	1,870,249	4	27,204	3	14.54	18	45,982	4	24.59	33	39.13	24
Oklahoma	535,399	17	5,779	19	10.79	31	13,910	20	25.98	29	36.77	30
Oregon	357,321	27	2,922	30	8.18	39	9,838	31	27.53	23	35.71	34
Pennsylvania	1,976,466	3	34,513	2	17.46	9	52,001	2	26.31	27	43.77	19
Rhode Island	168,888	39	2,778	32	16.45	11	3,495	41	20.69	42	37.14	29
South Carolina	287,913	31	1,633	41	5.67	47	11,462	25	39.81	9	45.48	17
South Dakota	180,632	36	1,983	38	10.98	30	4,102	38	22.71	37	33.69	40
Tennessee	398,624	25	4,173	25	10.47	32	19,231	16	48.24	3	58.71	6
Texas	1,548,343	6	20,263	7	13.09	24	42,747	5	27.61	22	40.70	23
Utah	127,004	42	1,097	45	8.64	37	3,478	42	27.38	24	36.02	31
Vermont	87,402	45	2,365	37	27.06	1	2,530	44	28.95	20	56.01	8
Virginia	441,462	19	6,134	18	13.89	21	16,621	18	37.65	10	51.54	10
Washington	523,328	18	3,262	29	6.23	45	15,431	19	29.49	19	35.72	33
West Virginia	275,691	32	5,498	20	19.94	4	9,397	32	34.09	12	54.03	9
Wisconsin	840,291	11	13,001	9	15.47	13	19,447	15	23.14	36	38.61	25
Wyoming	80,765	46	601	47	7.44	42	2,478	45	30.68	16	38.12	27
District of Columbia	162,863	----------	2,145	----------	13.17	----------	2,520	----------	15.47	----------	28.64	----------
1938 totals	29,485,680	----------	388,825	----------	13.19	----------	771,764	----------	26.17	----------	39.36	----------
1937 totals	29,705,220	----------	399,613	----------	13.45	----------	761,998	----------	25.65	----------	39.10	----------
Increase or decrease	−219,540 (−0.7 percent)		−10,788 (−2.7 percent on total)				9,766 (1.3 percent on total)				−0.1 percent on both totals	

[1] This tabulation is based on tables, State Motor-Fuel Tax Receipts, State Motor-Vehicle Registrations, and State Motor-Vehicle Receipts, 1938.

The figures in table 8 indicate that although motor-vehicle receipts in 1938 were well above those collected in 1930, the peak year of the 1929–31 period, receipts dropped much more rapidly after 1930 and again in 1938, than did passenger-car or truck registrations. In contrast, the percentage of increase in receipts in 1937 was much greater than the percentage of increase in registration of passenger cars or trucks.

WESTERN STATES HAVE LOWEST REGISTRATION FEES

It has been noted that motor-vehicle registrations in 1938 in 11 States were less than during the peak year of the 1929–31 period. In the case of motor-vehicle receipts this condition is even more pronounced, for 25 States in 1938 collected less from motor-vehicle imposts than they did in the peak year of the 1929–31 period. This included 3 of the 4 States in the Far West, Oklahoma and Texas in the Southwest, all but Colorado, Idaho, and Utah in the Northwest, 6 of the 12 States in the Southeast, only Connecticut, Massachusetts, and Vermont in the Northeast, and all but Illinois, Indiana and Ohio in the Middle States.

Many of these decreases are due to changes in basic registration rates since 1929 and a shift from registration fees to increased motor-fuel taxation as a source of funds for the support of highways. While the trend is not so pronounced today, there is some indication that for the present the general movement for lower registration fees is over, even though legislatures in several States during recent sessions considered various bills embodying downward revisions of registration fees for passenger cars. Since average registration fees in the different regions vary by almost 100 percent, it is reasonable to expect continued agitation for revision in the fees charged.

Table 9 shows that the average registration fees range from $7.11 in the Northwest States to $13.46 in the Northeast States. This regional comparison bears out the indications of figure 7 that the lowest average fees generally were collected in the Western States.

TABLE 8.—*Comparison of changes in registrations and motor-vehicle receipts, 1921–38*

Year	Increase or decrease in motor-vehicle receipts from previous year		Increase or decrease in registration of—	
	Amount	Percent	Passenger cars [1]	Trucks
	1,000 dollars		*Percent*	*Percent*
1922	29,569	24.1	16.3	23.0
1923	36,923	24.3	23.8	19.2
1924	36,521	19.3	14.7	32.8
1925	35,127	15.6	13.2	14.4
1926	27,663	10.6	9.9	13.2
1927	12,779	4.4	5.1	5.4
1928	21,569	7.2	5.7	6.9
1929	25,214	7.8	8.2	8.5
1930	7,861	2.3	−.3	3.1
1931	−11,367	−3.2	−3.1	−.6
1932	−20,064	−5.8	−6.5	−6.8
1933	−22,959	−7.1	−1.2	(2)
1934	5,945	2.0	4.3	5.8
1935	15,714	5.1	4.9	6.7
1936	36,809	11.4	7.1	9.3
1937	39,830	11.1	5.3	6.7
1938	−10,788	−2.7	−.7	−.7

[1] Includes busses.
[2] Less than 0.1 percent.

TABLE 9.—*Average motor-vehicle registration fees by regions, 1938*

Region	Average registration fee
Northeast	$13.46
Southeast	10.96
Southwest	10.92
Middle States	11.75
Northwest	7.11
Far West	7.69
United States	11.22

Table 10 gives the average registration fees and other motor-vehicle imposts collected in the several regions in 1921, 1930, and 1938. Differences in classification make it difficult to compare these regions satisfactorily for different years on any other basis than that of total motor-vehicle imposts collected. In many States, records were so maintained in 1921 that segregation of fees by types of vehicles as well as by miscellaneous types of fees could not be obtained. Unfortunately, for desirable comparisons which might be made, this is still true for many States.

The comparison in table 10 of average motor-vehicle imposts by regions in 1921, 1930, and 1938, indicates no pronounced trend in the average amount of such imposts collected since 1921. In all regions except the Far West, the average amounts collected in 1938 were above the average amounts collected in 1921, the greatest increase being in the Southwest, amounting to 35 percent. Much of this increase is due not to changes in registration fee schedules but to additional charges levied on motor-vehicle owners since 1921. For example, the licensing of operators and chauffeurs and the collection of fees therefor is much more widespread today than in 1921. Other charges such as fines and penalties and certificates of title and transfer fees, individually small but providing considerable sums of revenue, are included in the total of motor-vehicle imposts.

TABLE 10.—*Average registration fees and other motor-vehicle imposts per registered vehicle, by regions, in 1921, 1930, and 1938*

Region	Average fee in—		
	1921	1930	1938
Northeast	$13.82	$16.80	$16.79
Southeast	12.18	15.24	12.58
Southwest	9.13	10.66	12.35
Middle States	11.37	12.42	13.33
Northwest	8.13	10.17	8.21
Far West	12.48	9.84	8.86
United States	11.71	13.40	13.19

Analyses of motor-vehicle data will be materially aided when more uniform methods and classifications are adopted by the several States. At present, busses are sometimes included with passenger-car registrations, sometimes with trucks, sometimes shown separately; and the segregation of such registrations at the end of the registration year is usually not economically practicable. Similar conditions exist with reference to certain types of trucks registered with passenger cars and with reference to certain types of commercially operated passenger cars registered with trucks.

There has been marked improvement in registration practice in recent years as far as the segregation of vehicles by types is concerned but much improvement is still possible in the segregation of registration fees by types of vehicles. Table 6 indicates that in five States no segregation is possible. Moreover, the reported segregations are believed to be of doubtful accuracy in other States. However, analysis of the existing data, unsatisfactory as they are in certain respects, makes possible the general observations and conclusions noted in this discussion and suggests that further study of social, economic, and demographic factors in the United States will reveal other important relationships to motor-vehicle statistics.

HIGHWAY RESEARCH BOARD WILL MEET IN DECEMBER

The Nineteenth Annual Meeting of the Highway Research Board of the National Research Council will be held in Washington, D. C., Tuesday to Friday, December 5–8, 1939. Reports on highway research investigations will be presented, and the formal meetings of the Board will be supplemented with open meetings for informal discussion of pertinent topics. A program of reports will be announced by the Board about November 1.

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF SEPTEMBER 30, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	NUMBER: Grade Crossings Eliminated by Separation or Relocation	NUMBER: Grade Crossing Structures Reconstructed	NUMBER: Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 491,450	$ 479,159	4	1		$ 767,612	$ 766,084	12			$ 32,908	$ 32,700		1	2	$ 826,692
Arizona						518,061	515,813	6								209,120
Arkansas	189,891	189,891	3			68,938	68,938	1			639,990	633,485	4		8	577,263
California	398,219	398,219	4			1,384,358	1,383,263	7			137,560	137,560	2		1	1,165,815
Colorado	309,307	309,305	3		11	306,992	306,992	2			48,514	44,754			14	791,132
Connecticut						172,722	161,008		1							850,557
Delaware						9,150	9,150	2			2,320	2,320			1	513,891
Florida						643,232	642,396	4			7,800	7,800			2	1,016,395
Georgia	56,530	56,530	3			370,750	370,750	4			315,346	315,346	5	3	20	2,123,394
Idaho						314,492	282,961	4								466,886
Illinois	1,580,055	1,579,195	8	2	29	2,073,480	1,950,092	13	2	21	131,050	105,955			37	2,051,037
Indiana	316,903	316,903	2		45	680,850	680,850	2	1	25	513,919	513,919	1	2	32	790,758
Iowa	313,878	295,800	7			191,842	161,006	7		10	686,446	642,800	1		168	1,003,068
Kansas	404,329	404,329	6		4	943,832	943,832	9		1	237,831	237,831	3		3	897,466
Kentucky	149,212	149,212	3	2		626,864	626,864	9	2		630,607	630,607	4		4	515,950
Louisiana	122,838	122,830	2			490,999	490,989	5			651,161	597,659	12			584,469
Maine	264,771	264,771	2	2		271,066	271,066	3	1							236,310
Maryland	24,510	15,402				275,795	179,002	2		2	46,200	46,200			13	986,891
Massachusetts	265,259	264,538	1	2		257,307	256,764	3			14,320	14,320	1			1,711,447
Michigan	194,426	194,426	2	1		977,150	977,150	6	1		310,220	310,220	2		39	1,543,746
Minnesota	163,676	163,646	1	3	6	1,222,692	1,202,541	7	3	6	192,473	191,433	3		5	1,364,578
Mississippi						611,373	611,373	8			37,300	37,300	1			889,528
Missouri	65,589	64,284	1			1,197,536	1,197,536	7	1		775,239	710,060	3	5		1,338,080
Montana	439,450	439,450	4			624,130	509,049	8								284,589
Nebraska	28,481	28,481	1			1,124,383	1,124,383	24	1		149,270	149,270			41	637,289
Nevada	122,064	122,064		1	1	72,234	72,234		1	7	11,577	11,577			5	113,530
New Hampshire	15,305	15,305	3		1	147,279	146,776	5			51,837	51,837	2			307,567
New Jersey						737,456	737,456	2	3	1						1,439,345
New Mexico	59,805	59,805	2			15,276	15,276				2,572	2,572			1	682,071
New York	809,800	807,450	1	4		2,414,022	2,376,472	11	9		542,933	400,813	1	2		3,419,903
North Carolina	506,240	506,240	4	1	16	1,027,390	992,290	9	4	6	186,930	186,930		1	43	846,675
North Dakota	105,450	105,450	3	1		818,489	770,087	9			75,960	75,960	1			391,201
Ohio	241,760	241,760	4			1,365,783	1,329,021	10	2		639,920	590,730	3	1	2	2,901,510
Oklahoma	267,055	266,955	2		32	183,725	183,725	3		10	220,700	207,900	2	1	8	2,014,297
Oregon	21,689	21,689				148,072	146,777	1			135,740	135,740	2			311,060
Pennsylvania						2,161,799	1,949,900	5	3		702,857	494,405	3	1	2	4,218,923
Rhode Island	327,613	327,613	1	2		111,178	111,178		1							152,459
South Carolina	98,810	65,428	2	1		586,856	564,520	6	4		262,279	262,279	2	2	35	780,994
South Dakota	67,040	67,040		1	7	332,420	332,420	4	2	10	47,550	47,550	1			1,005,070
Tennessee	73,600	73,600		1	1	632,746	632,746	2	2	2	179,620	179,620	1	1	2	1,326,544
Texas	726,135	725,800	6	1		2,283,130	2,252,002	20	2		572,319	503,830	4		26	1,911,733
Utah	82,650	82,650	2		20	125,198	125,198	1		45	213,310	213,310			79	175,910
Vermont	32,489	27,676			6	4,032	4,032			1	118,940	118,940		1		199,307
Virginia	195,562	195,562	2		11	531,513	438,613	7	2	5	109,256	109,256		1	4	923,325
Washington	35,507	35,506			5	295,956	294,546	3	1	3	60,782	60,782		1	4	514,672
West Virginia	40,817	40,817				334,034	318,274	7			24,200	24,200	1		3	958,494
Wisconsin	335,448	334,617	5		1	1,189,040	1,145,011	10	1	4	341,541	336,847	1	2	9	950,823
Wyoming	40,626	40,470	1		7	98,543	98,543		1							516,862
District of Columbia						292,412	258,868	1			74,400	74,400				44,918
Hawaii	50,320	50,320	1			132,850	132,850	3	1							359,450
Puerto Rico	49,040	48,840	1			345,312	343,310	8								426,676
TOTALS	10,083,599	9,999,028	97	26	203	32,512,351	31,461,977	282	52	159	10,135,697	9,451,017	66	25	613	50,269,670

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF SEPTEMBER 30, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 1,419,026	$ 704,435	80.8	$ 8,239,554	$ 4,097,698	279.8	$ 520,090	$ 259,040	10.2	$ 2,683,476
Arizona	393,055	262,718	12.6	1,879,258	1,322,913	90.0	709,475	447,524	36.4	904,668
Arkansas	1,766,060	1,765,115	133.0	1,686,701	1,658,251	89.6	85,631	83,150	2.7	1,696,477
California	4,105,120	2,241,010	53.9	2,654,076	1,448,733	37.9	1,558,518	812,071	35.1	3,154,770
Colorado	1,013,767	554,704	25.1	3,608,403	2,016,061	81.7	464,920	234,769	17.1	1,799,439
Connecticut	357,558	176,334	5.1	1,880,711	935,261	17.9	176,447	87,811	2.0	1,166,556
Delaware	456,831	225,935	12.0	1,311,331	640,107	26.2	208,316	104,158	.3	1,018,460
Florida	121,000	60,500	1.4	3,893,470	1,946,511	67.0	896,393	448,196	13.8	2,500,284
Georgia	2,296,600	1,148,300	123.3	6,375,253	3,187,626	332.0	1,461,411	730,706	70.5	5,238,060
Idaho	1,337,479	803,955	56.5	1,378,889	839,260	70.2	335,689	176,791	42.7	1,092,894
Illinois	2,027,248	1,006,240	41.9	9,273,775	4,635,841	190.7	2,257,930	1,127,375	59.8	2,782,680
Indiana	2,028,266	1,014,133	35.3	5,654,834	2,802,817	130.1	1,363,774	681,762	22.1	1,800,458
Iowa	1,097,129	512,074	68.5	5,803,838	2,581,483	202.5	284,982	133,625	9.7	935,894
Kansas	1,326,445	655,517	67.0	3,438,215	1,718,228	174.5	2,631,828	1,315,914	137.9	4,182,783
Kentucky	1,324,019	662,010	42.8	3,529,810	1,763,349	95.8	894,180	447,090	23.1	2,828,763
Louisiana				12,212,226	3,151,747	53.3	1,289,631	624,124	37.3	2,596,998
Maine	1,151,290	575,286	21.2	1,687,170	843,585	45.8	23,360	11,680	.5	322,718
Maryland	1,155,690	548,711	19.0	2,644,573	1,307,905	39.4	487,000	239,500	8.3	1,796,410
Massachusetts	2,529,677	1,263,104	18.6	820,626	409,358	6.5	1,737,109	865,037	12.1	2,482,079
Michigan	1,605,321	773,982	37.9	4,687,281	2,341,001	142.7	1,114,810	409,880	24.4	2,780,254
Minnesota	1,710,526	845,601	103.9	6,331,663	3,142,809	357.5	2,048,113	1,022,966	87.5	3,046,876
Mississippi	631,000	231,470	35.1	8,649,588	3,184,995	348.9	933,100	448,050	21.6	2,151,301
Missouri	1,124,969	561,802	43.2	4,832,386	2,397,484	182.1	2,883,263	1,167,400	77.8	4,144,443
Montana	657,051	370,857	42.6	3,095,327	1,751,875	152.6	669,089	379,505	37.4	4,142,038
Nebraska	272,839	136,420	31.5	6,752,521	3,375,612	583.4	1,646,619	823,310	191.8	2,675,130
Nevada	927,829	802,281	43.1	709,242	609,648	30.0	409,491	352,209	17.0	729,568
New Hampshire	98,756	48,285	4.0	1,257,038	617,621	29.9	427,033	211,357	14.6	849,313
New Jersey	538,290	269,145	6.0	4,028,848	2,012,874	29.8	459,840	229,920	2.2	1,808,846
New Mexico	891,754	546,888	76.6	1,226,520	751,434	58.5	259,102	161,705	31.1	1,372,235
New York	3,361,580	1,653,997	64.5	13,440,309	6,588,408	229.3	2,521,750	1,082,785	31.7	1,427,095
North Carolina	1,728,670	862,255	103.5	7,000,203	3,492,617	380.4	395,780	193,490	21.1	1,525,401
North Dakota	87,260	46,736	17.1	1,325,469	710,291	96.4	2,241,260	1,201,261	244.7	3,372,887
Ohio	1,149,720	574,860	13.2	10,001,476	4,932,024	110.1	2,246,760	1,101,687	22.5	6,386,295
Oklahoma	708,559	375,209	5.9	2,895,525	1,536,496	103.8	2,230,520	1,186,465	89.9	3,244,489
Oregon	807,310	490,870	34.5	2,770,347	1,674,927	131.8	1,220,045	566,648	19.4	1,352,271
Pennsylvania	2,789,564	1,378,205	39.9	9,656,285	4,659,067	87.3	2,269,893	1,124,738	32.2	3,946,942
Rhode Island	300,790	150,275	4.2	517,736	258,681	6.0	647,521	323,235	5.9	910,008
South Carolina	1,145,840	516,200	52.2	1,716,194	761,287	34.0	232,000	98,000	24.8	2,397,197
South Dakota	1,570,025	861,560	134.8	3,749,899	2,095,600	360.2	1,075,150	608,160	113.6	3,178,828
Tennessee	618,580	309,290	15.5	4,023,864	2,011,932	110.3	458,698	229,349	9.8	4,246,863
Texas	5,757,839	2,838,675	352.3	8,607,749	4,260,263	368.5	2,037,596	1,005,300	97.7	6,038,518
Utah	1,075,365	774,250	46.9	1,474,670	1,065,935	81.3	128,925	92,740	2.0	838,437
Vermont	543,111	267,281	11.9	210,948	104,734	6.6	164,000	82,000	4.9	615,414
Virginia	1,125,870	560,870	32.9	2,919,747	1,419,640	73.6	681,457	335,014	21.6	1,000,657
Washington	1,410,072	734,800	17.8	2,297,579	1,199,257	28.8	1,450,676	602,058	10.1	722,895
West Virginia	568,977	321,150	19.7	2,753,255	1,393,865	62.7	856,777	424,083	29.3	1,819,165
Wisconsin	2,342,651	1,146,023	101.1	7,346,868	3,626,860	218.9	606,750	294,765	23.8	1,637,610
Wyoming	716,787	444,071	79.0	917,797	566,162	76.0	941,766	594,331	104.6	583,947
District of Columbia				198,624	99,312	1.2	257,500	128,750	1.9	259,438
Hawaii	139,685	66,970	1.0	1,005,840	480,750	16.4	568,447	280,803	9.8	1,051,180
Puerto Rico	302,230	150,315	6.4	1,567,819	778,155	31.2	163,352	80,795	1.8	365,530
TOTALS	62,615,080	33,290,674	2,396.2	205,941,330	101,208,350	6,561.1	51,633,767	25,673,082	1,970.1	111,604,938

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION
(Formerly the *BUREAU OF PUBLIC ROADS*)

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938. 10 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. . Roadside Improvement. 10 cents.

No. 272MP. . Construction of Private Driveways. 10 cents.

No. 279MP. . Bibliography on Highway Lighting. 5 cents.

Highway Accidents. 10 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Transition Curves for Highways. 60 cents.

Highways of History. 25 cents.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T. . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP. . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, Volumes 6–19, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration (formerly the *Bureau of Public Roads*), classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF SEPTEMBER 30, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 186,105	$ 91,750	13.7	$ 885,145	$ 354,900	22.9	$ 78,300	$ 39,150	6.3	$ 739,456
Arizona	56,191	40,524	11.0	241,691	173,791	22.4				325,941
Arkansas	328,755	324,677	39.7	266,508	261,812	37.6	153,862	153,756	17.6	276,875
California	151,277	85,419	17.1	990,834	507,423	31.2	219,075	117,065	4.9	645,261
Colorado	211,957	108,270	10.1	694,169	367,583	23.3	108,036	43,368	.2	67,572
Connecticut				172,794	72,417	2.9	108,041	37,810	.2	248,439
Delaware	80,840	40,420	17.5	71,661	35,830	7.8				232,384
Florida	123,817	61,550	3.4	865,805	428,544	34.2	7,358	3,679		371,271
Georgia	168,617	83,378	21.0	317,740	158,870	38.3	165,599	82,800	22.3	1,058,626
Idaho	127,733	76,396	4.9	310,653	166,378	36.9	138,206	70,687	10.1	123,412
Illinois	589,113	294,216	18.5	1,247,200	569,600	88.7	431,700	213,795	30.0	586,506
Indiana	300,200	150,100	25.8	826,970	412,281	64.1	130,926	65,463	9.7	660,414
Iowa	24,095	11,069	22.9	296,129	139,410	31.1	738,581	346,825	107.6	1,182,503
Kansas	7,806	3,903	6.0	159,712	79,856	38.6	411,025	210,292	9.3	1,286,782
Kentucky	199,808	66,485	31.2	1,142,618	311,560	60.3	696,256	246,918	56.6	223,613
Louisiana	322,110	154,055	28.4	430,351	194,455	32.8	356,361	154,721	29.6	329,341
Maine	282,703	141,280	16.2	202,820	100,324	11.8	19,700	9,850	1.2	9,067
Maryland	197,291	94,987	14.5	11,296	5,648	1.5	263,000	84,555	14.1	350,491
Massachusetts	101,519	50,435	2.4	243,465	120,729	5.2	341,556	169,241	7.5	449,264
Michigan	275,490	132,202	10.0	1,266,090	630,545	110.4	342,108	171,054	26.4	803,053
Minnesota	284,968	142,347	23.8	701,916	349,051	66.1	232,118	116,059	41.1	1,051,048
Mississippi	176,500	88,250	6.8	636,062	292,246	45.2	271,400	145,700	32.5	624,670
Missouri	215,534	105,775	41.2	782,154	381,177	85.8	553,987	225,340	62.0	554,866
Montana	111,913	63,475	10.8	702,330	398,292	58.3	61,970	35,149	6.9	835,112
Nebraska	445,634	212,802	84.4	802,179	394,532	141.5				380,221
Nevada	160,777	139,268	25.0	70,067	60,261	18.1	57,534	28,767	9.6	142,327
New Hampshire	61,156	29,708	2.4	2,192	1,096		111,620	53,835	3.1	135,325
New Jersey	87,010	43,300	2.9	393,530	194,230	16.8	94,300	47,150	4.7	507,278
New Mexico	159,661	97,765	9.8	339,901	208,610	32.4	370,828	152,394	26.9	70,687
New York	692,736	341,609	35.4	2,128,960	997,052	93.8	687,380	269,240	6.5	321,249
North Carolina	470,594	235,275	37.0	965,730	482,865	94.4	6,030	2,500	1.0	326,205
North Dakota	115,030	61,606	8.3				148,770	79,717	10.9	819,207
Ohio	94,160	47,080	6.1	870,960	440,945	43.9	236,000	118,000	7.1	1,689,327
Oklahoma	73,190	38,943	.8	217,196	115,568	11.8	501,355	266,763	32.8	906,171
Oregon	243,134	146,330	30.8	554,456	282,952	57.3	35,927	16,820	3.0	291,366
Pennsylvania	1,578,647	777,647	96.7	1,297,656	642,723	46.7	454,542	227,271	15.4	221,917
Rhode Island	93,827	46,890	2.2	81,236	40,618	.2	36,060	18,030	.4	78,277
South Carolina	504,587	204,690	48.8	79,320	34,379	8.2	330,400	142,044	22.2	204,807
South Dakota				16,170	8,890	4.1				1,049,160
Tennessee	472,560	197,110	24.3	261,456	130,728	7.7				858,499
Texas	1,448,151	686,551	172.9	1,104,202	536,220	91.9	83,340	41,550	17.3	1,055,553
Utah	123,645	71,116	22.7	97,955	51,747	12.8	17,800	12,000	4.0	197,199
Vermont	91,158	45,153	4.0	222,662	78,983	7.8				52,328
Virginia	472,654	228,831	47.2	268,130	132,429	23.8	229,030	105,050	14.6	209,027
Washington	387,157	201,942	19.8	383,574	201,118	29.1	103,829	53,400	11.2	211,542
West Virginia	145,150	72,575	8.4	13,015	6,507		165,676	82,838	8.6	430,576
Wisconsin	403,848	201,709	22.4	690,232	344,457	13.3	324,158	157,423	7.9	545,669
Wyoming	402,460	248,619	22.3	231,836	146,343	14.1	111,591	64,828	19.5	58,196
District of Columbia				14,592	6,796	.1	109,600	54,800	1.1	11,529
Hawaii	90,660	45,330	3.8	205,590	102,795	4.6	179,480	89,705	6.4	82,170
Puerto Rico				224,465	109,130	12.8	55,188	27,140	2.1	60,233
TOTALS	13,341,928	6,832,812	1,135.3	25,003,375	12,264,696	1,744.6	10,279,603	4,854,542	732.4	23,952,012

U. S. GOVERNMENT PRINTING OFFICE 1939