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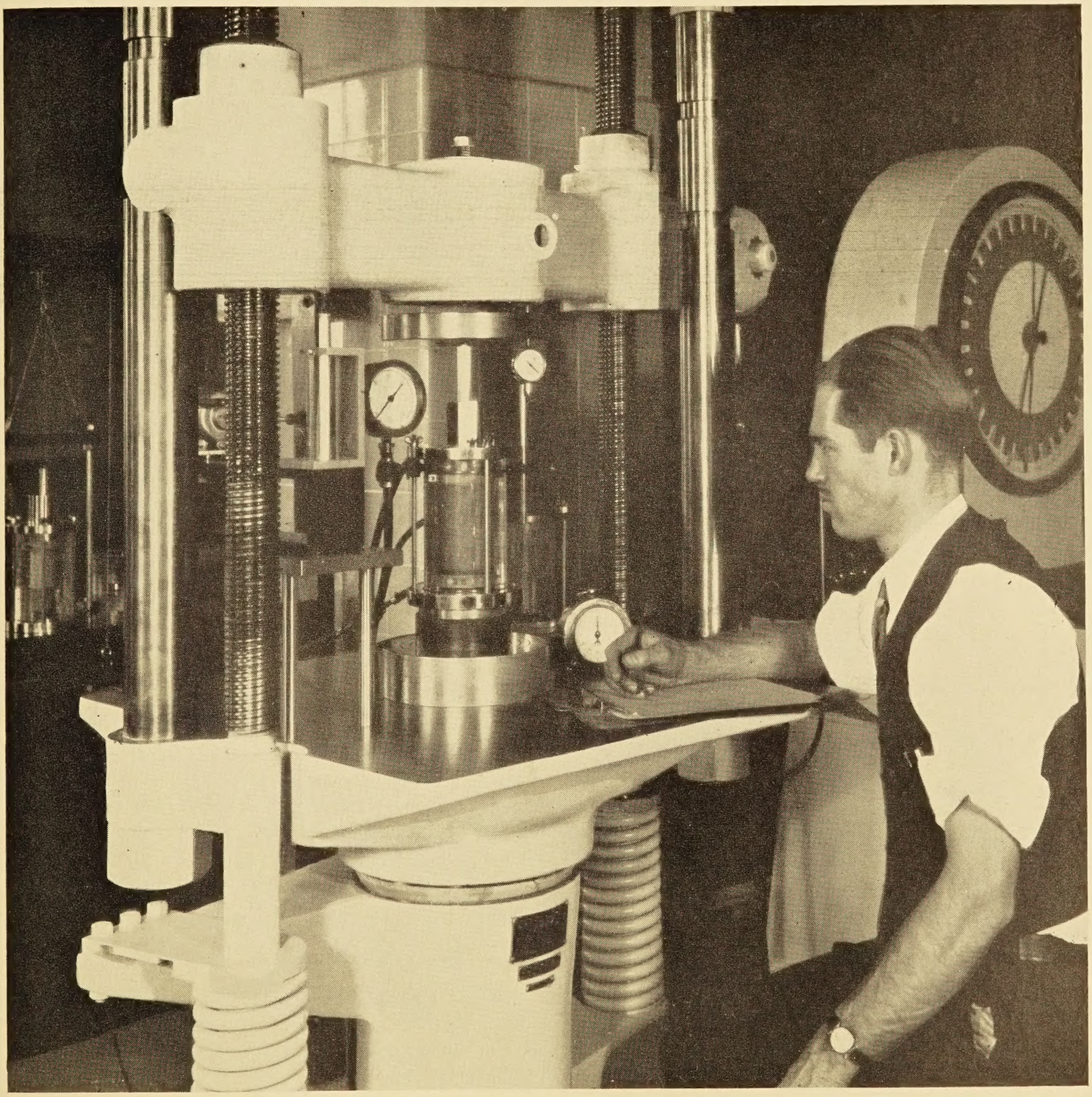

LABORATORY DETERMINATION OF SOIL STABILITY

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THE SETTLEMENT OF EARTH EMBANKMENTS

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTATION

Reported by **L. A. PALMER**, Associate Research Specialist, and **E. S. BARBER**, Junior Highway Engineer

ONE of the most important considerations in the design of highway embankments is the amount of settlement that may be expected. Methods of estimating settlement caused by soil consolidation due solely to loss of water from compressible foundation soils have already been described.[1] The present report is chiefly concerned with settlement resulting from lateral displacement of soil, designated as S_L, as distinguished from settlement caused by consolidation, designated as S_C.

The question of ultimate supporting power has been considered at length in three previous publications [2] [3] [4] and the analyses are made with reference to ultimate fill loads that will cause the supporting earth to fail completely, that is, deform without any definite limit. Obviously, however, more information is required for the satisfactory design of embankments.

For example, it is entirely possible for a high fill to subside several feet due to displacement in the supporting soil but without the occurrence of failure in that supporting soil. Assumption in the design that a large factor of safety against ultimate failure will assure one that displacement by lateral yield will be a small quantity may not accomplish the desired result. Hogentogler and Allen [5] have pointed out the fallacy of such an assumption and have proposed the use of values, c' and ϕ', which are certain percentages of the unit cohesion c, and the angle of internal friction ϕ, respectively, which appear in formulas for computing the supporting power of the earth below the fill. This procedure is based on the use of the complete shearing stress-deformation relation instead of ultimate values.

PLASTIC YIELD ASSUMED INSTEAD OF ELASTIC DEFORMATION

In continuation of this study, it is proposed to make use of a principle presented by A. Nadai [6] called the "stationary flow of a plastic mass." This principle leads to the development and use of formulas that are similar to the expressions for Hooke's law for elastic bodies but which differ from Hooke's law in that plastic yield is assumed in the place of elastic deformation.

The basic principle involved in this report is a simple one and is that a certain earth movement, too small to be comparable to displacements characteristic of failure of the earth itself, may ruin a structure. More specifically, the fill load may be much too small to cause failure of the supporting earth, yet it may be large enough to be disastrous to the highway. In brief, it is necessary to estimate S_L. For this purpose two things are needed: A ratio of stress to deformation, herein designated as C, the modulus of deformation, which has no reference to the nature of the deformation, whether it be elastic or plastic deformation or both; and a value of Poisson's ratio, μ.

Experimental work has indicated that the value of μ for compressible types of soil may vary from 0.35 for soils containing much air to 0.50 for soils that are saturated with water.

For the cases in which μ is less than $\frac{1}{2}$, it is very likely that the small soil samples undergo some degree of volume diminution owing to the escape of air or water during the stabilometer test. It cannot, however, be concluded that the same volume change occurring in such tests can take place as readily and quickly in large earth masses. Therefore, it has been customary to take μ as $\frac{1}{2}$ in computing S_L in large earth masses even though the laboratory value of μ is not this quantity, and this value of μ is used in computing S_L in this report.

Figure 1 illustrates the essential features of the laboratory stabilometer used in the study of stresses within a cylindrical soil sample. The stabilometer is often referred to as the "triaxial shear test device." Several types of this device and the principles governing their use have been described by Hogentogler and Barber.[7]

In stabilometer tests, cylindrical soil samples, encased in rubber sleeves, are compressed to complete failure by the application of vertical load. During the loading there may be no lateral pressure on the specimen (a simple compression test in this case) or a variable or a constant lateral pressure may be applied from start to finish of the test. The test may be made with or without porous stones at the flat ends of the cylindrical samples.

The vertical load is applied through the plunger by means of a hydraulic testing machine. At the beginning of a test, the head of the machine is lowered until contact is made with the plunger, as shown in the cover illustration, and the platen and head of the machine remain fixed in position until loading is begun. A definite fluid pressure is then applied to the sample, figure 1, through the inlet valve. Since the machine is fixed in position the lateral fluid pressure tends to push a saturated sample upward against the plunger with a variable force depending on the mobility of the sample. For a saturated soft soil, the vertical and lateral pressures may become equal under these initial conditions. When the sample contains much air the fluid pressure tends to compress the air or cause its escape thus shortening the sample without increasing its diameter.

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[1] The Theory of Soil Consolidation and Testing of Foundation Soils, by L. A. Palmer and E. S. Barber. PUBLIC ROADS, vol. 18, No. 1, March 1937.

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

[3] Principles of Soil Mechanics Involved in the Design of Retaining Walls and Bridge Abutments, by L. A. Palmer, PUBLIC ROADS, vol. 19, No. 10, Dec. 1938.

[4] Design of a Fill Supported by Clay Underlaid by Rock, L. A. Palmer. PUBLIC ROADS, vol. 20, No. 8, Oct. 1939.

[5] Important Considerations in Soil Mechanics, by C. A. Hogentogler and Harold Allen, Bulletin, American Society for Testing Materials, No. 94, Oct., 1938.

[6] Plasticity (chapter 14, pp. 75 to 79, incl.), A. Nadai. Engineering Societies Monographs, McGraw-Hill Book Company, Inc., first edition, 1931.

[7] Essential Features of Triaxial Shear Tests, by C. A. Hogentogler and E. S. Barber. PUBLIC ROADS, vol. 20, No. 7, Sept., 1939.

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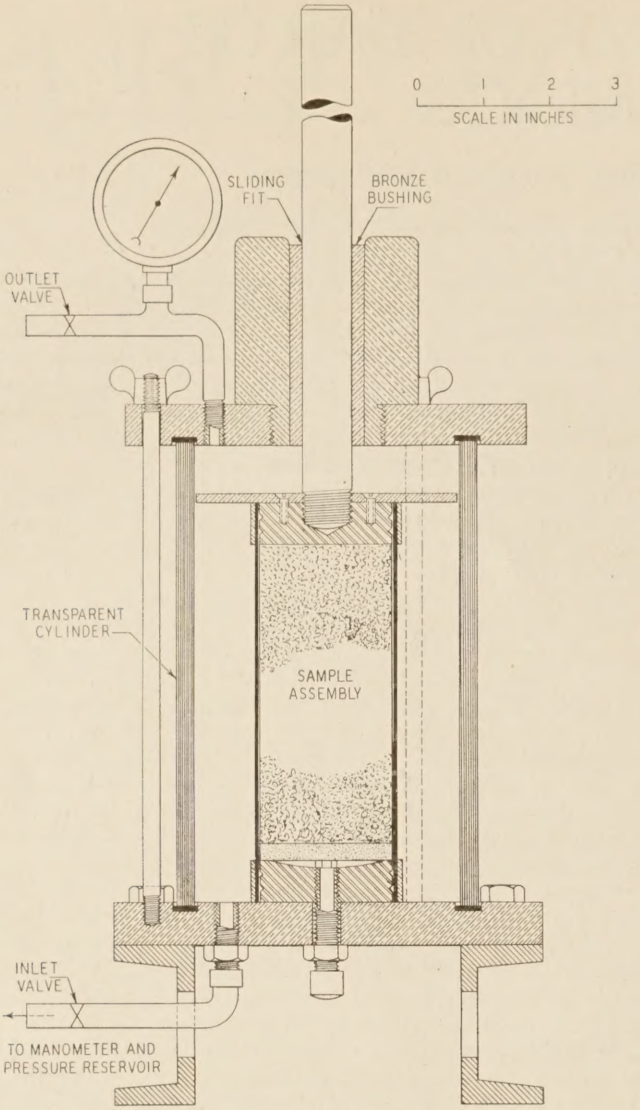

Figure 1.—Stabilometer of the Plunger Type.

Vertical load is then increased by elevating the platen at a constant rate of 0.05 inch per minute. An automatic recording device gives the complete vertical load versus change in height curve for the entire test. Any change from the initial height, h, is designated as Δh.

For the plotted data shown in this paper, the soil cylinders were 1.95 inches in diameter and the height, h, was 4 inches. Porous stones, sometimes placed at the two flat ends of the sample, were not used in these tests.

MODULUS C DETERMINABLE FROM STABILOMETER TEST DATA

During a quick stabilometer test, a relatively impermeable and saturated soil undergoes deformation without appreciable volume change. If, however, the soil contains air, loading tends to compress the air, according to Boyle's law, with consequent reductions of volume and height of the sample.

The known decrease in height due either to compression of air or its escape is not considered as deformation in computing the modulus of deformation, C. In computing this modulus, it is assumed that the soil deforms at constant volume in which case μ, Poisson's ratio, is ½.

Reference is made to figure 2, which illustrates three distinctly different types of soil behavior during the early period of loading in the stabilometer or triaxial compression device. In figure 2–A, with a lateral pressure of 6,000 pounds per square foot, the developed vertical pressure with the machine in fixed position was also 6,000 pounds per square foot. The point, $l=v=6{,}000$ therefore falls on the axis of v, vertical pressure, which is the axis of zero $\frac{\Delta h}{h}$. Figure 2–B illustrates another type of behavior. Here the developed v with the machine in fixed position was 5,600 pounds per square foot with l, the lateral pressure, equal to 6,000. The point A for $l=v=6{,}000$ is not on the $\frac{\Delta h}{h}=0$ axis but corresponds to a value of 0.0004 for $\frac{\Delta h}{h}$. Figure 2–C illustrates still another type of behavior. Here the developed v with the machine in fixed position was 5,200 for $l=6{,}000$ and under this system of initial stresses, the height h decreased until the value of $\frac{\Delta h}{h}$ became 0.0075. Then as load was applied and v was increased, the sample began to deform. At the point A for $v=l=6{,}000$, $\frac{\Delta h}{h}$ is seen to be 0.0089.

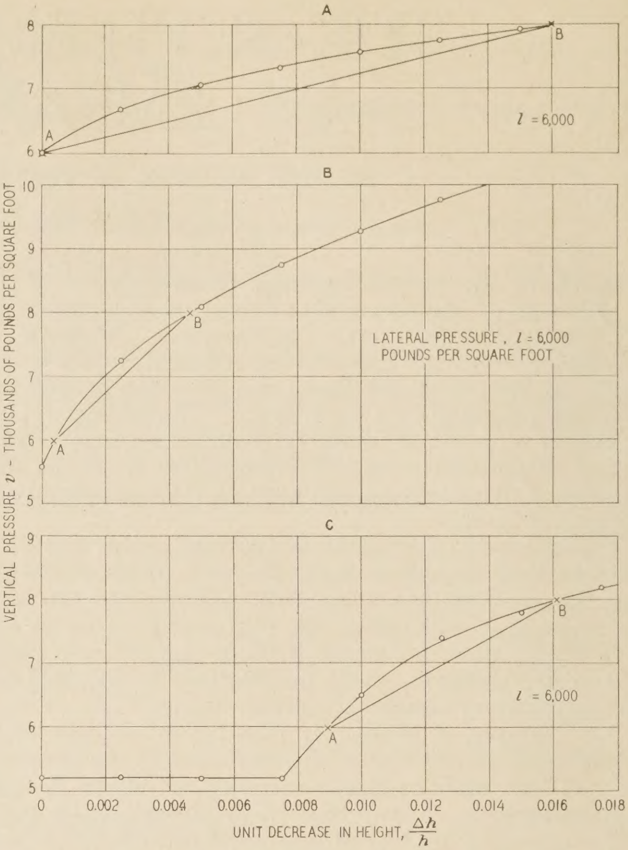

Figure 2.—Stress-Strain Curves From Triaxial Compression Tests.

Figure 2–A is characteristic of a relatively soft saturated soil of low permeability; figure 2–B is characteristic of a relatively stiff saturated soil of low permeability; and figure 2–C is characteristic of a stiff soil that contains an appreciable volume of air.

The horizontal distance from the point A, where $l=v$, to the $\frac{\Delta h}{h}=0$ axis is zero for curve A in figure 2, 0.0004 for curve B, and 0.0089 for curve C. These variable distances denote reductions in h due to volume changes without distortion and therefore represent small consolidations of the sample that are usually unavoidable, appear in their entirety, and are completely accounted for in consolidation tests. Thus the horizontal distances from A to the $\frac{\Delta h}{h}=0$ axis properly fall in the category of S_C settlement. The change in $\frac{\Delta h}{h}$ beyond the point A is indicative of distortion without volume change (S_L settlement).

The modulus of deformation, C, is taken as a secant modulus in this paper and is the slope of the secant line drawn from the initial point A, figure 2, where $l=v$, to another point B, determinable from the conditions of the particular problem. Since there are an infinite number of points beyond A, there may be an infinite number of secant lines and of moduli C. There is but one secant line, however, for a specific problem fixing the point B. Thus the nature of the problem may be such that the value of $v-l$ at the point B is 2,000 pounds per square foot. This is illustrated in figure 2. If $l=6{,}000$ and $v-l=2{,}000$, then $v=8{,}000$, the ordinate value of the point B, figure 3. In figure 2–A, the slope of AB is $\frac{8{,}000-6{,}000}{0.016-0}=125{,}000$ pounds per square foot$=C$. In figure 2–B, the slope of AB is $\frac{8{,}000-6{,}000}{0.0047-0.0004}=465{,}000$ pounds per square foot $=C$. In figure 2–C, the slope of AB is $\frac{8{,}000-6{,}000}{0.0161-0.0089}=$ 278,000 pounds per square foot$=C$, rounding the value of C to the nearest 1,000 pounds per square foot.

For any vertical load greater than that corresponding to the initial point, A, figure 2, it is necessary to correct for the changed horizontal cross-sectional area of the deformed sample in computing v. This correction is contained in the following expression for v:

$$v=\frac{P}{A}\left(1-\frac{\Delta h}{h}\right)+l \text{ ---------------------------- } (1)$$

where P is the net load, equal to the load on the plunger plus the weight of the plunger minus the product of the lateral pressure, l, and the cross-sectional area, a, of the plunger stem. A is the initial cross-sectional area of the sample.

SETTLEMENT OF FILL UNDER ITS OWN WEIGHT CONSIDERED

Figure 3 illustrates a symmetrical earth fill with equal slopes. The Y direction is the direction of the length of the fill which is perpendicular to the plane of the figure. If the fill is long in comparison with its width, displacement in the Y direction is zero. The Z direction is the vertical one and OZ (fig. 3) is the axis of symmetry of any vertical cross section that is assumed to be of unit thickness in the Y direction. In the plane of the diagram (fig. 3) the X direction is horizontal. The directions are indicated by the coordinates, X, Y, and Z. The origin, 0, is at the base of the fill and on the vertical axis of symmetry. The letters x, y, and z denote both direction and distance whereas X, Y, and Z denote direction only. The normal stresses p_x and p_z act in the X and Z directions, respectively, and their values at any point depend upon the coordinates x and z of the point. The shearing stress, s_{zx}, acts in the X direction and in a plane to which the Z direction is perpendicular. The shearing stress, s_{xz}, acts in the Z direction and in a plane to which the X direction is perpendicular. For a condition of equilibrium, $s_{xz}=s_{zx}$.

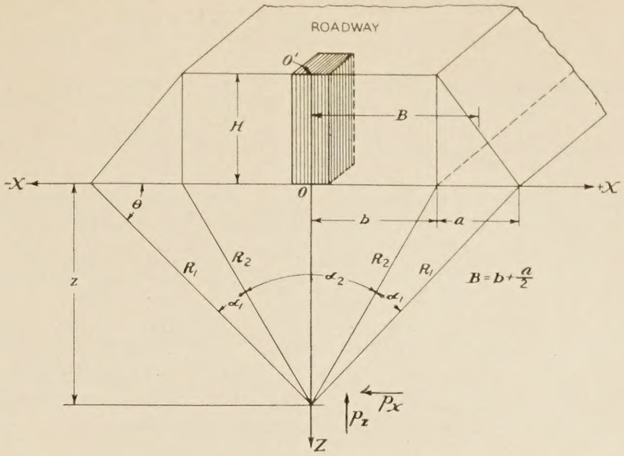

Figure 3.—Diagram of Symmetrical Earth Fill.

The fill problem, figure 3, involves two dimensions, that is, only soil movements in the X and Z directions are of concern. The letter V designates the displacement of a particle at a point (x, z) in the Z direction and U designates the displacement of the particle at the same point in the X direction. The rate of change of V with respect to z, when x is constant, is $\frac{\partial V}{\partial z}$ and denotes the strain in the Z direction. The rate of change of U with respect to x, at constant z, is $\frac{\partial U}{\partial x}$, the strain in the X direction. The strain in the Y direction is zero. The problem is one of plane strain or deformation. From Hooke's law and Nadai's principle,

$$\frac{\partial V}{\partial z}=\frac{1}{C}[p_z-\mu(p_x+p_y)] \text{ -------------- } (2)$$

$$\text{strain in } Y \text{ direction}=0=\frac{1}{C}[p_y-\mu(p_x+p_z)] \text{ -------- } (3)$$

and

$$\frac{\partial U}{\partial x}=\frac{1}{C}[p_x-\mu(p_y+p_z)] \text{ ------------- } (4)$$

Nadai refers to C as a "constant" rather than a modulus and, for a material that undergoes distortion without change in volume, takes μ as 1/2.

Then, according to Nadai's principle, applicable to flow in a plastic mass, equation 2 would become

$$\frac{\partial V}{\partial z}=\frac{1}{C}[p_z-1/2(p_x+p_y)] \text{ ----------- } (5)$$

Consider the column of earth, 00′ on the vertical axis of symmetry in figure 3. For the present, consider the origin as moved from 0 to 0′. Any vertical distance, z, is then considered as directed downward from the roadway which is the horizontal plane containing 0′. Let w denote the weight per cubic foot of fill material assumed to be homogeneous. Then at any depth z in the column 0′0, $p_z=wz$ and $p_x=K'wz$ where K' is the ratio of lateral to vertical pressure at the depth z. From equation 3

$$p_y=\mu(p_x+p_z)=\mu(K'wz+wz)$$

Substituting this value for p_y in equation 2

$$\frac{\partial V}{\partial z}=\frac{1}{C}\left[wz-\mu(K'wz+\mu K'wz+\mu wz)\right]$$

or

$$\frac{\partial V}{\partial z}=\frac{wz}{C}\left[1-\mu K'-\mu^2(K'+1)\right]\text{--------}(6)$$

Integrating equation 6, assuming K' constant,

$$V=\frac{wz^2}{2C}\left[1-\mu K'-\mu^2(K'+1)\right]+f(x)\text{------}(7)$$

On the axis of symmetry, $f(x)$, a function of x alone, becomes a constant, K_1, and for points on this axis,

$$V=\frac{wz^2}{2C}\left[1-\mu K'-\mu^2(K'+1)\right]+K_1\text{------}(8)$$

If it is assumed that $V=0$ at $z=H$, a condition which will exist if the undersoil is unyielding and there is only the settlement S_L of the fill to consider, K_1 may then be evaluated so that equation 8 becomes

$$V=\frac{w}{2C}(z^2-H^2)[1-\mu K'-\mu^2(K'+1)]\text{-------}(9)$$

and for $\mu=1/2$,

$$V=\frac{3w}{8C}(1-K')(z^2-H^2)\text{-----------}(10)$$

Here V denotes the downward displacement of a soil particle on the axis of symmetry and at any depth z from the roadway. The greatest vertical displacement is at $z=0$ at $0'$. At this point,

$$V=S_L=-\frac{3w}{8C}H^2(1-K')\text{-----------}(11)$$

The use of equation 11 is limited by the fact that there is no sure way of determining K'. Theoretically, its value is greater than 0 and less than 1. If $K'=0$ is taken, then S_L is a maximum value and on the side of safety.

SETTLEMENT S_L OF THE UNDERSOIL DETERMINED

The origin is now taken at the point 0, figure 3. The angles, α_1 and α_2 of figure 3 are expressed in radians and from the diagram it is evident that

$$2\alpha_1+\alpha_2=2\text{ arc cot }\frac{z}{a+b}$$

and

$$\alpha_1=\text{arc cot }\frac{z}{a+b}-\text{arc cot }\frac{z}{b}.$$

It has been shown [2] that on the axis of symmetry, OZ,

$$p_z=\frac{p}{\pi}\left(2\alpha_1+\alpha_2+\frac{2b}{a}\alpha_1\right)\text{-------------}(12)$$

and

$$p_x=\frac{p}{\pi}\left(2\alpha_1+\alpha_2+\frac{2b}{a}\alpha_1-\frac{4z}{a}\log_e\frac{R_1}{R_2}\right)\text{-------}(13)$$

where p_x and p_z are normal stresses (at any depth z on OZ) due solely to the fill load.

From equation 3, $p_y=\mu(p_x+p_z)$ and substituting this value for p_y in equation 2,

$$\frac{\partial V}{\partial z}=\frac{1}{C}[p_z-\mu(p_x+\mu p_x+\mu p_z)]\text{---------}(14)$$

By substituting equations 12 and 13 in 14 one obtains

$$\frac{\partial V}{\partial z}=\frac{p}{\pi C}\left[(1-\mu-2\mu^2)\left(2\text{ arc cot }\frac{z}{a+b}+\frac{2b}{a}\text{ arc cot }\frac{z}{a+b}-\frac{2b}{a}\text{ arc cot }\frac{z}{b}\right)+\mu(1+\mu)\frac{4z}{a}\log_e\frac{\sqrt{(a+b)^2+z^2}}{\sqrt{b^2+z^2}}\right]\text{(15)}$$

It must be remembered that on integrating equation 15, it is desired to know V on the axis of symmetry and hence, $x=0$. The last term of equation 15 is the only one giving difficulty in integration. This may be integrated by parts and by the transformation,

$$z=(a+b)\tan\theta$$

where θ is the angle shown in figure 3.

The vertical displacement, V, of a soil particle at the point 0, figure 3, and S_L, are identical in magnitude. In general, however, V refers to the vertical displacement of a particle at any point and not just at 0. Hence, it is a special value of V, namely its value at 0, the sum of all the strains from 0 to a given depth z, that is equal to S_L.

By, integration of equation 15 between the limits, 0 and z, one obtains

$$\begin{aligned}V\text{ at }0=\frac{p}{\pi C}\Bigg\{&(1-\mu-2\mu^2)\left(2+\frac{2b}{a}\right)\left[z\text{ arc cot }\frac{z}{a+b}+\frac{a+b}{2}\log_e\left(1+\frac{z^2}{(a+b)^2}\right)\right]\\&-(1-\mu-2\mu^2)\left(\frac{2b}{a}\right)\left[z\text{ arc cot }\frac{z}{b}+\frac{b}{2}\log_e\left(1+\frac{z^2}{b^2}\right)\right]\\&+\frac{4\mu(1+\mu)}{a}\left[\frac{z^2}{2}\log_e\frac{\sqrt{z^2+(a+b)^2}}{\sqrt{z^2+b^2}}+\frac{(a+b)^2}{2}\log_e\frac{\sqrt{z^2+(a+b)^2}}{a+b}-\frac{b^2}{2}\log_e\frac{\sqrt{z^2+b^2}}{b}\right]\Bigg\}\text{-----}(16)\end{aligned}$$

S_L denotes the diminution in thickness of a given depth of undersoil due to lateral displacement, and
for $\mu=1/2$ equation 16 reduces to

$$S_L=V\text{ at }0=\frac{3p}{\pi Ca}\left[\frac{z^2}{2}\log_e\frac{\sqrt{z^2+(a+b)^2}}{\sqrt{z^2+b^2}}+\frac{(a+b)^2}{2}\log_e\frac{\sqrt{z^2+(a+b)^2}}{a+b}-\frac{b^2}{2}\log_e\frac{\sqrt{z^2+b^2}}{b}\right]\text{------}(17)$$

It is convenient to obtain solutions of equations 12 and 16 by graphical methods. With reference to figure 3, let $B=b+\frac{a}{2}$. Then for $a=0$, the trapezoidal load becomes a uniform strip load and $\frac{b}{B}=1$. For $b=0$, the load diagram becomes triangular and $\frac{b}{B}=0$. All of the possible symmetrical trapezoidal load diagrams are then contained within the limiting cases, $\frac{b}{B}=0$ and $\frac{b}{B}=1$. Now write for equation 12,

$$p_z=pf$$

where $f=\frac{1}{\pi}\left(2\alpha_1+\alpha_2+\frac{2b}{a}\alpha_1\right)$.

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[2] See footnote 2, p. 161.

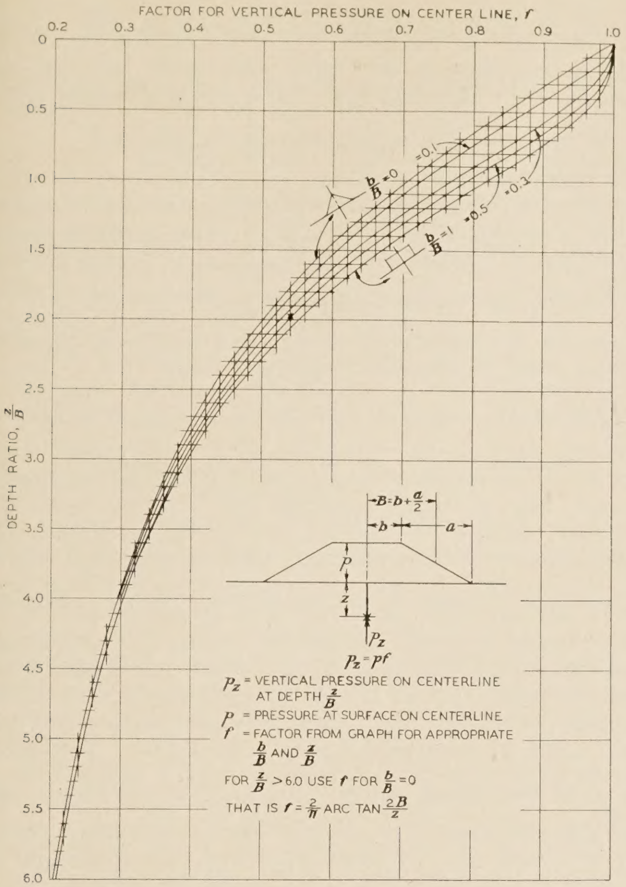

Figure 4.—Graph of Vertical Pressure on Centerline Under a Symmetrical Fill.

The value of f depends on the depth z of any point on the centerline and on the distances, a and b (fig. 3). The curves in figure 4 are obtained by plotting values of f against the "depth ratio," $\frac{z}{B}$. The five curves of this figure are for the ratios of $\frac{b}{B}$ equal to 0, 0.1, 0.3, 0.5, and 1.0. For ratios that are intermediate, a value for f corresponding to a given $\frac{z}{B}$ ratio may be obtained by interpolation. For depths such that $\frac{z}{B}$ exceeds 6.0, the value for f is taken from the formula for $\frac{b}{B}=0$, regardless of what the actual value of $\frac{b}{B}$ may be since there is practically complete coincidence of all the curves at $\frac{z}{B}=6.0$.

In fills having the same B and the same height, H, the vertical cross-sectional area is the same. Hence, it is convenient to use the value B as a basis for constructing charts such as figure 4 for use in computations.

Equation 16 may be written

$$S_L=\frac{p}{C}\left(b+\frac{a}{2}\right)F=\frac{pB}{C}F \text{-----------} (18)$$

where

$$F=\frac{1+\mu}{\pi(1-b/B)}\Bigg\{(1-\mu)\Bigg[(2-b/B)^2\log_e\sqrt{1+\frac{(z/B)^2}{(2-b/B)^2}} - (b/B)^2\log_e\sqrt{1+\frac{(z/B)^2}{(b/B)^2}}\Bigg] + \mu(z/B)^2\log_e\sqrt{\frac{(z/B)^2+(2-b/B)^2}{(z/B)^2+(b/B)^2}} + (1-2\mu)z/B\left[(2-b/B)\text{ arc cot }\frac{z/B}{2-b/B}-(b/B)\text{ arc cot }\frac{z/B}{b/B}\right]\Bigg\}$$

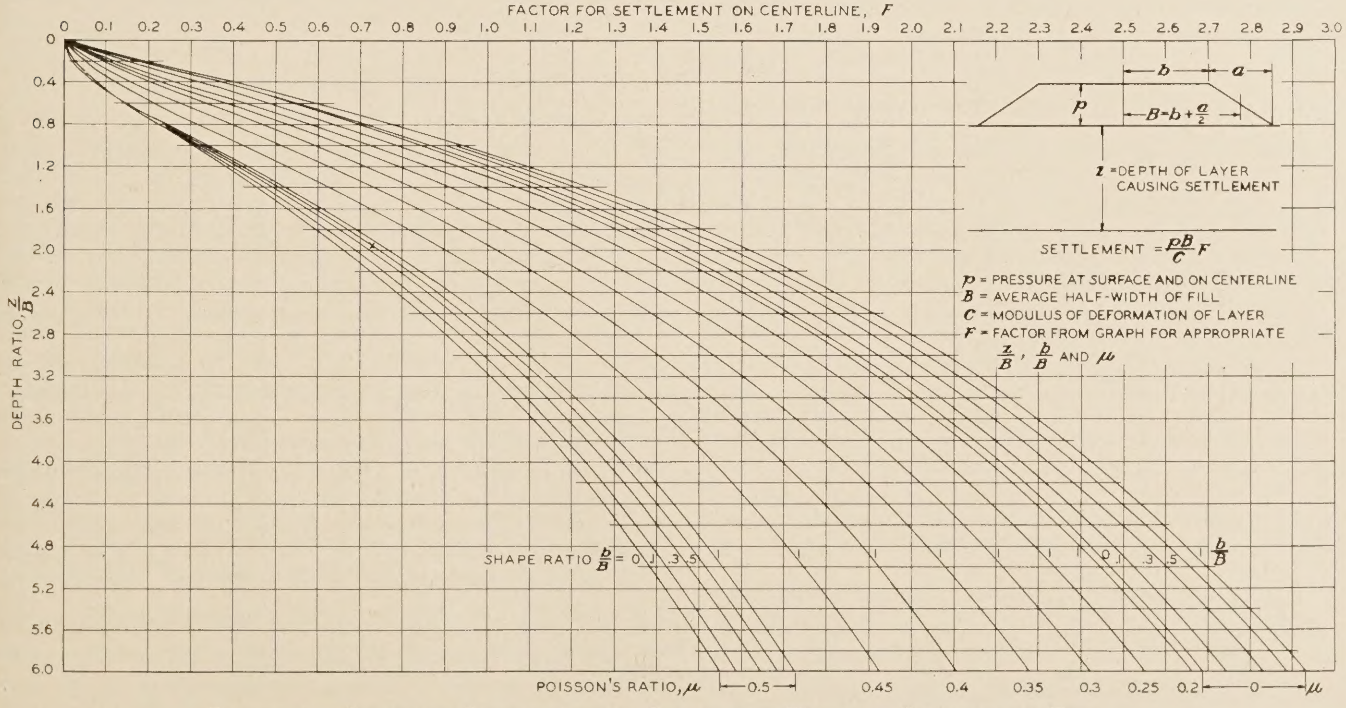

Figure 5.—Graph of Settlement on Centerline Under a Symmetrical Fill.

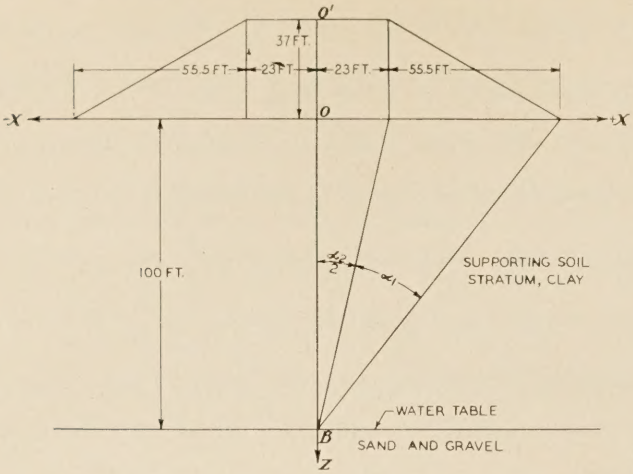

Figure 6.—Symmetrical Fill Supported by Clay.

The value of F in equation 18 depends on μ, Poisson's ratio. The curves of figure 5 were constructed for values of μ varying from 0 to ½ by plotting values of $\frac{z}{B}$ against F for different values of $\frac{b}{B}$. A numerical example will be given illustrating the use of the chart, figure 5.

COMPUTATION OF S_L ILLUSTRATED

Consider the fill, figure 6, of height, $H=37$ feet, with a 1½ to 1 slope and supported by a clay stratum 100 feet thick which is underlaid by sand and gravel. The supporting soil and fill material have different properties. The average weight per cubic foot of the compacted fill material is $w=126$ pounds. The width of the roadway is 46 feet so that b (fig. 3) is 23 feet. The distance, a, is $1\frac{1}{2}\times 37=55.5$ feet. The value of $B=b+\frac{a}{2}=23+\frac{55.5}{2}=50.8$ feet and the ratio, $\frac{b}{B}$, is $\frac{23}{50.8}=0.453$. The value of p is $wH=37\times 126=4{,}662$ pounds per square foot. The thickness of the deformable clay layer is 100 feet and the depth ratio, $\frac{z}{B}$, is $\frac{100}{50.8}=1.97$.

In previous publications [2 3] it has been shown that the greatest shearing stress anywhere in the undersoil below a symmetrical fill is $0.32\ p$. This greatest shearing stress is located at a distance equal approximately to B below the point 0, figure 3, and is equal to $\frac{1}{2}\ (v-l)$ where v is the vertical pressure and l the lateral pressure at the point of greatest shearing stress.

Then since $\frac{1}{2}\ (v-l)=0.32\ p$, $v-l=0.64\ p$ and theoretically this is the greatest $v-l$ value that exists anywhere in the supporting earth below the embankment. For $p=4{,}662$ pounds per square foot, the greatest value of $v-l$ is $0.64\times 4{,}662=2{,}984$ pounds per square foot. With reference now to figure 7 which shows the v versus $\frac{\Delta h}{h}$ characteristics of the undersoil for $l=0$ and $l=4{,}180$ pounds per square foot, the point B is determined for each curve. For $v-l=2{,}984$, when $l=0$, $v=2{,}984$ and for $l=4{,}180$, $v=2{,}984+4{,}180=7{,}164$ pounds per square foot. The ordinate values of B are then 2,984 for $l=0$ and 7,164 for $l=4{,}180$. The value of $\frac{\Delta h}{h}$ at the initial point A for $l=0$ is -0.0001. The initial point A for $l=4{,}180$ is at that point of the upper curve where $v=l=4{,}180$. For $l=4{,}180$, the slope of AB, upper curve of figure 2, is $\frac{7{,}164-4{,}180}{0.0310-0.0036}=109{,}000$ pounds per square foot $=C$. For $l=0$, the slope of AB,

(Continued on page 172)

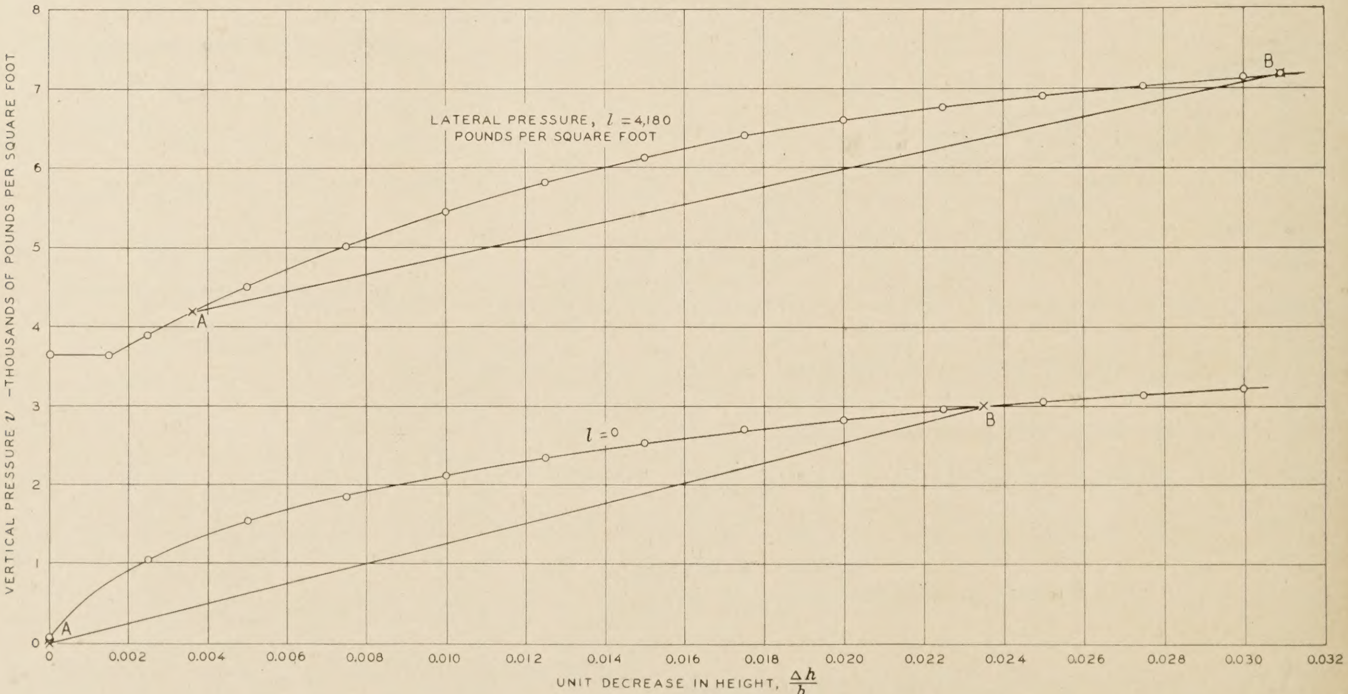

Figure 7.—Triaxial Test Data for Foundation Soil.

[2 3] See footnotes 2 and 3, p. 161.

HORIZONTAL FORCES AND MOMENTS ON BRIDGE ABUTMENTS AND RETAINING WALLS

EFFECT OF CONCENTRATED MOVING LIVE LOADS ON THE BACKFILL

Reported by **E. I. FIESENHEISER**, Assistant Bridge Engineer, District 4, Public Roads Administration

THE PURPOSE of this paper is to present methods of computing the overturning effect of live loads by taking into account the distribution of stresses through the soil. The paper presents:

(1) Exact equations for the force and moment based on the theoretical variation of stress.
(2) Simplified approximate equations sufficiently accurate for most cases.
(3) A determination of the position of the live load for maximum moment.
(4) Charts for use in computing.

In designing bridge abutments and retaining walls the horizontal pressure of the backfill material on the wall must be taken into account. The amount of this pressure and its overturning moment are usually determined by assuming that the pressure increases uniformly with the depth of fill. This assumption results in either a triangular or trapezoidal pressure diagram.

In dealing with the problem of truck wheels or concentrated live loads on top of the backfill or roadway it is customary to assume an added depth of fill or surcharge. The loads are assumed to be distributed over an area and the depth of surcharge is taken as the depth of a volume of backfill material equal to the loads in weight.

The moment effect of the live loads upon the wall has been a matter for conjecture and the method of adding a surcharge has doubtless been used for lack of a better or more precise method. However, recent experiment and progress in the field of soil mechanics have pointed the way to a very different solution of this problem.

STRESS DISTRIBUTION EQUATIONS DEVELOPED

When taking into account the stress distribution in the soil reference is usually made to the work of Joseph Boussinesq, a noted elastician, who derived equations for the stresses in the interior of an elastic solid. The conditions assumed by Boussinesq are a semi-infinite, elastic, isotropic solid bounded by a plane surface upon which a single concentrated load acts in a direction perpendicular to the plane surface. Published equations,[1] give the normal and shearing components of stress in the interior of the solid. However, these stress components are only those acting on planes parallel to the surface plane.

Assuming the horizontal surface of the backfill to be the boundary plane and keeping in mind that the plane of the wall or abutment is vertical, an expression is needed for the horizontal component of stress acting upon a plane perpendicular to the surface plane. Such an expression in terms of rectangular coordinates with the origin at the load point is $\sigma_x=\frac{3P}{2\pi}\frac{x^2z}{(x^2+y^2+z^2)^{5/2}}$, for the stress in the x-direction, the z-axis being vertical and the x- and y-axes horizontal. This is a simplified expression derived by assuming the term Poisson's ratio equal to one-half, which is in accordance with a fundamental principle of soil mechanics that the soil particles are incompressible or incapable of a change in volume. Equations from which it is derived may be found in texts on the theory of elasticity.[2]

Actual working conditions for which the above expression would be applicable would be a soil of perfect elasticity with elastic properties the same in all directions (conditions of an isotropic soil). Some soils may very nearly approach these conditions, while others may be far from elastic and isotropic. However, with regard to retaining walls, experiments have indicated that the shape of the pressure variation curve is similar to that obtained from the theoretical expression and that the quantitative differences may be taken into account by the use of empirical constants dependent upon the type of soil.

In experiments on retaining walls conducted at the Iowa Engineering Experiment Station, Ames, Iowa, by M. G. Spangler [3] the horizontal pressure due to concentrated surface loads was measured. By transforming the theoretical expression an empirical equation was devised which gives pressure intensities corresponding to the measured intensities. The equation devised is $h_c=\frac{kP}{x^n}\frac{x^2z}{(x^2+y^2+z^2)^{5/2}}$ in which k is a constant depending upon the type of soil and n is a constant depending upon the relative rigidity of the wall and backfill. Obviously more experimenting is needed with different types of soil before values of these constants can be determined for all cases, since these experiments were made with gravel only.

HORIZONTAL FORCES AND OVERTURNING MOMENTS COMPUTED

In applying the equation to the computation of horizontal forces and overturning moments working values of k equal to 1.3 and n equal to 1/4 will be used, assuming a gravel backfill and conditions similar to those in the experiments conducted by Spangler. If values for k and n can be determined for other materials and conditions, such values may be substituted in the equations to be derived. Forces and moments will be directly proportional to the constant k and inversely to x^n, x being the distance from the load to the wall. (See fig. 1.)

As shown in figure 1, with the origin directly under the load, the coordinates of a point on the wall are x, y, and z, where

x=horizontal distance from the load to the wall.
y=horizontal distance from the load parallel to the wall.
z=vertical distance below the top of the fill.
$R=\sqrt{x^2+y^2+z^2}$.
P=the concentrated load.

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[1] Application des Potentiels a L'etude de L'equilibre et du Mouvement des Solides Elastique, by M. J. Boussinesq. Gauthier-Villars. Paris. 1885. p. 104.

[2] For the solution in terms of cylindrical coordinates see Theory of Elasticity, by S. Timoshenko. McGraw Hill, New York. 1934. pp. 328-331.

[3] Horizontal Pressures on Retaining Walls Due to Concentrated Surface Loads, b M. G. Spangler. Iowa Engineering Experiment Station Bulletin 140. 1938.

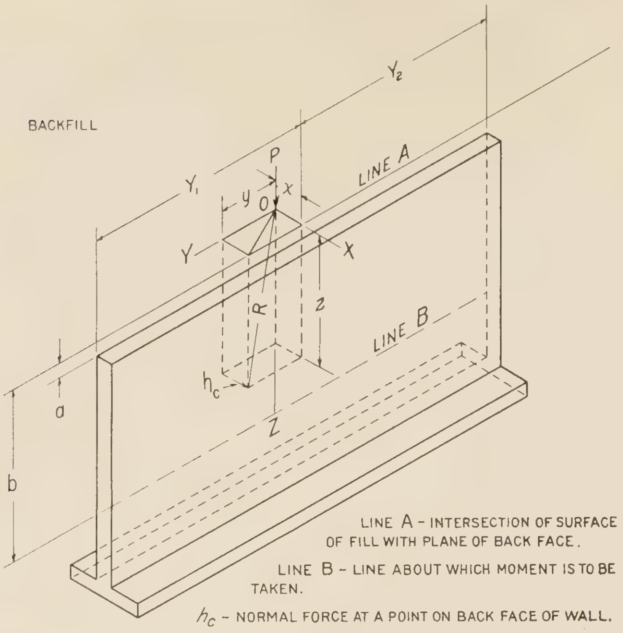

FIGURE 1.—DIAGRAM SHOWING RETAINING WALL AND LOAD ON BACKFILL.

a=vertical distance from top of fill to top of wall.
b=vertical distance from top of fill to a horizontal line where the moment is desired.
M=moment at the line b distance below top of fill.
H=total horizontal force acting on the wall above the line.
h_c=intensity of horizontal pressure at any point on the wall.

To get a clear picture of the stress variation expressed by the equation, curves may be plotted holding x and y constant while z varies (see fig. 2) and holding x and z constant while y varies (see fig. 3).

In dealing with a bridge abutment attention is called to the fact that the top or surface of the backfill is not always at the top of the wall. A part of the earth pressure may be taken by the floor slab or diaphragms at the end of the bridge and transferred as a thrust through the superstructure. In such a case only the horizontal force acting on the area of the wall unit is of interest. Accordingly a distance a from the surface of the fill to the top of the wall is introduced to take care of this condition.

Referring to figure 2, $h_c=\frac{kP}{x^n}\cdot\frac{x^2z}{(x^2+y^2+z^2)^{5/2}}$

The differential area of wall $dA=dy\ dz$ and the force

$$dH=h_cdA=\frac{kP}{x^n}\cdot\frac{x^2zdydz}{(x^2+y^2+z^2)^{5/2}}$$

Taking as z-limits the distances b and a and as y-limits the distances Y_1 and Y_2,

$$H=kPx^{(2-n)}\int_a^b\int_{Y_2}^{Y_1}\frac{zdydz}{(x^2+y^2+z^2)^{5/2}}\text{------------------}(1)$$

Integrating in z-direction and substituting limits,

$$H=\frac{kPx^{(2-n)}}{3}\left\{\int_{Y_2}^{Y_1}(a^2+x^2+y^2)^{-\frac{3}{2}}dy-\int_{Y_2}^{Y_1}(b^2+x^2+y^2)^{-\frac{3}{2}}dy\right\}$$

Integrating this expression in the y-direction and substituting limits,

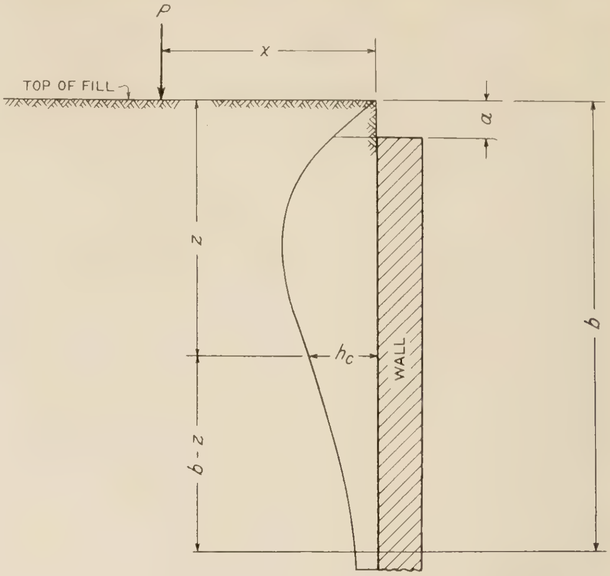

FIGURE 2.—STRESS VARIATION, x AND y CONSTANT.

$$H=\frac{kPx^{(2-n)}}{3}$$

$$\left\{Y_1\left[\frac{1}{(a^2+x^2)\sqrt{a^2+x^2+Y_1^2}}-\frac{1}{(b^2+x^2)\sqrt{b^2+x^2+Y_1^2}}\right]\right.$$

$$\left.-Y_2\left[\frac{1}{(a^2+x^2)\sqrt{a^2+x^2+Y_2^2}}-\frac{1}{(b^2+x^2)\sqrt{b^2+x^2+Y_2^2}}\right]\right\}\text{-}(2)$$

In deriving an equation for the overturning moment the differential of moment about a line b distance below the top of fill is

$$dM=\frac{kP}{x^n}\frac{x^2z(b-z)dydz}{(x^2+y^2+z^2)^{5/2}}$$

and the total moment

$$M=\frac{kPx^2}{x^n}\int_a^b\int_{Y_2}^{Y_1}\frac{z(b-z)dydz}{(x^2+y^2+z^2)^{5/2}}\text{---------}(3)$$

Integrating first in the z-direction and substituting the limits b and a,

$$M=\frac{kPx^{(2-n)}}{3}\int_{Y_2}^{Y_1}\frac{1}{(x^2+y^2)}$$

$$\left[\frac{a^3+bx^2+by^2}{(a^2+x^2+y^2)^{3/2}}-\frac{b}{(b^2+x^2+y^2)^{1/2}}\right]dy$$

Integrating now in the y-direction, substituting the limits Y_1 and Y_2, and simplifying, the total moment becomes

$$M=\frac{kPx^{(2-n)}}{3}[(a^3+bx^2)A+b(C-B)]\text{-------}(4)$$

in which

$$A=\frac{1}{a^2}\left(\frac{\alpha}{ax}-\frac{\gamma}{a^2+x^2}\right)\text{-------------}(5)$$

$$B=\frac{\phi}{bx}\text{--------------------------}(6)$$

$$C=\frac{1}{a^2}\left(\gamma-\frac{x\alpha}{a}\right)\text{------------------}(7)$$

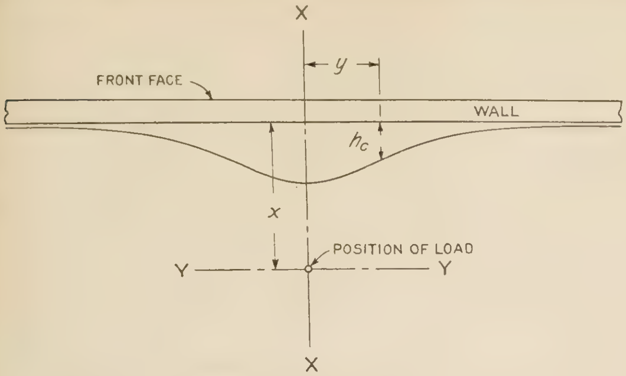

FIGURE 3.—STRESS VARIATION, x AND z CONSTANT.

and

$$\gamma=\frac{Y_1}{\sqrt{a^2+x^2+Y_1^2}}-\frac{Y_2}{\sqrt{a^2+x^2+Y_2^2}} \quad \text{------------------} \quad (8)$$

$$\alpha=\tan^{-1}\left[\frac{a}{x}\frac{Y_1}{\sqrt{a^2+x^2+Y_1^2}}\right]-\tan^{-1}\left[\frac{a}{x}\frac{Y_2}{\sqrt{a^2+x^2+Y_2^2}}\right] \quad (9)$$

$$\phi=\tan^{-1}\left[\frac{b}{x}\frac{Y_1}{\sqrt{b^2+x^2+Y_1^2}}\right]-\tan^{-1}\left[\frac{b}{x}\frac{Y_2}{\sqrt{b^2+x^2+Y_2^2}}\right] \quad (10)$$

Referring to equations 8, 9, and 10 it should be noted that Y_1 and Y_2 are distances measured parallel to the wall from the load to the ends of the wall. When the load is between the ends, which will ordinarily be the case, Y_1 will be assumed positive and Y_2 negative. The result will be the addition of the two terms in obtaining the value of the angles α and ϕ and the term γ. Angles α and ϕ are expressed in radians. When computing these angles if a conversion table is not at hand the angles may first be found in degrees and decimals of a degree from tables of natural functions, then multiplied by the constant 0.017453 to change degrees to radians.

For the particular case when the top of the fill coincides with the top of the wall the term a becomes zero. To obtain the moment the original expression, equation 3, may be integrated direct between limits b and 0. An alternate method is to substitute zero for a in the final equations 4 to 10. In the latter case the result will be zero divided by zero for the terms A and C. These indeterminate forms may be evaluated in the usual manner by differentiating. Taking third derivatives of numerators and denominators the values of the fractions can be found. By either method the resulting equation will be:

For $a=0$,

$$M=\frac{kPx^{(2-n)}}{3}\cdot b(D-B) \quad \text{---------------} \quad (11)$$

in which the term

$$D=\frac{Y_1}{x^2\sqrt{x^2+Y_1^2}}-\frac{Y_2}{x^2\sqrt{x^2+Y_2^2}} \quad \text{----------} \quad (12)$$

EQUATIONS APPLIED TO BRIDGE ABUTMENT PROBLEM

Equations 2 and 4 are expressions for the force and its overturning moment caused by a single load P concentrated at a point and placed at x distance from the wall. If the familiar principle of superposition is applied when there are more loads than one to deal with, the effects of the loads may be added together and the total moment will be the sum of the moments produced by the individual loads.

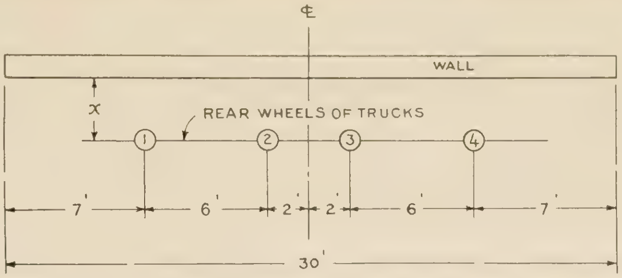

FIGURE 4.—PLAN OF ABUTMENT WALL, SHOWING POSITION OF REAR WHEELS OF 2 TRUCKS.

In applying the above equations to a bridge abutment a structure carrying two 10-foot traffic lanes is assumed. An abutment wall at least 30 feet long will ordinarily be required to support the two-lane superstructure. Such an arrangement of rear truck wheels as that indicated in figure 4 may be assumed.

Using the 30-foot wall as a basis for computing, a large number of solutions were worked out for the moment using different values for b and a. These computations revealed the fact that for relatively small values of a or x there is not much difference in the effect produced by wheels 1 and 4 and that produced by wheels 2 and 3. For example this difference was found to be less than 1 percent for the values $b=30$ feet and $a=0.5$ foot. In dealing with a wall of this length or greater it will usually be sufficiently accurate to compute the moment for a single load and multiply the result by the number of loads to obtain the total effect.

It can be seen that a single computation of force and moment by the above equations involves considerable work. Fortunately it is possible to derive much simpler equations which will be sufficiently accurate for the average wall. In a problem of this kind unnecessary refinements in calculation cannot be justified, especially if values of the soil constants cannot be determined with great exactness. The accuracy of the final result will depend upon experimental values of k and n. If infinite limits are assumed for y, letting $Y_1=+\infty$ and $Y_2=-\infty$, the following expressions are obtained:

$$H=\frac{2kPx^{(2-n)}}{3}\left[\frac{1}{a^2+x^2}-\frac{1}{b^2+x^2}\right] \quad \text{---------------} \quad (13)$$

$$M=\frac{2kPx^{(1-n)}}{3}\left[\frac{(b-a)x}{a^2+x^2}+\tan^{-1}\frac{a}{x}-\tan^{-1}\frac{b}{x}\right] \quad \text{----} \quad (14)$$

For $a=0$, equation (14) becomes

$$M=\frac{2kPx^{(1-n)}}{3}\left[\frac{b}{x}-\tan^{-1}\frac{b}{x}\right] \quad \text{-----------------} \quad (15)$$

It will be found that for a problem such as that of figure 4 equations 13, 14, and 15 will give results only slightly greater than those obtained from the exact equations 2 and 4 to 10, particularly for relatively small values of a and x. For example, for the values $b=30$ feet, $a=0.5$ foot, $x=1.18$ feet, the moment computed by equation 14 was found to be less than 1 percent greater than that computed by equations 4 to 10. Moments and forces determined by the simpler

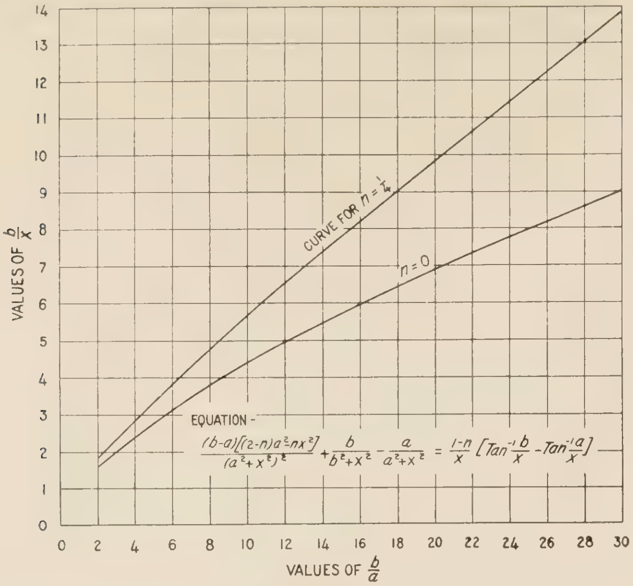

FIGURE 5.—CURVES SHOWING POSITION OF LOAD FOR MAXIMUM MOMENT, $a>0$.

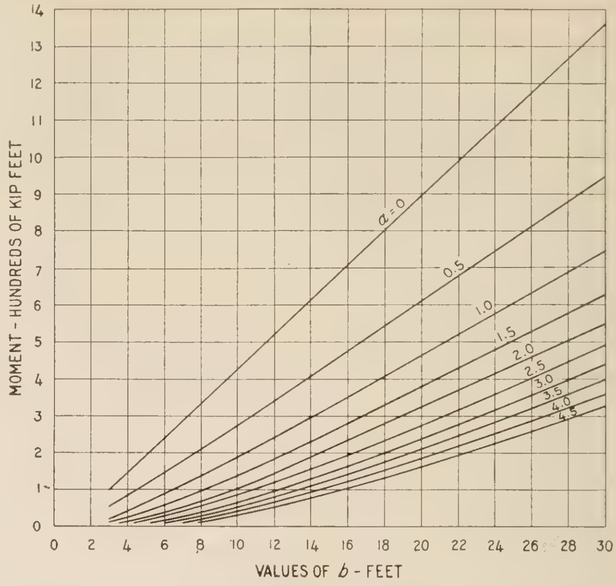

FIGURE 6.—MAXIMUM OVERTURNING MOMENTS AT VARIOUS DISTANCES FROM TOP OF FILL FROM THE REAR WHEELS OF TWO H-15 TRUCKS, $k=1.3$, $n=\frac{1}{4}$.

expressions will be on the safe side and it is believed that their use is justified.

Up to this point in the discussion the distance x has been treated only as a constant. However, for live loads moving toward or away from an abutment there is a value of x for which the moment is a maximum. To derive an equation for this value of x, equation 14 may be differentiated with respect to x and the result equated to zero. Performing these operations the following expression is obtained:

$$\frac{(b-a)[(2-n)a^2-nx^2]}{(a^2+x^2)^2}+\frac{b}{b^2+x^2}-\frac{a}{a^2+x^2}=\frac{1-n}{x}\left(\tan^{-1}\frac{b}{x}-\tan^{-1}\frac{a}{x}\right) \qquad (16)$$

Substituting known values for b and a in the equation enables solving for x. Placing the load at this distance from the wall will then produce the maximum moment. If the value of n is taken as $\frac{1}{4}$, equation 16 becomes

$$\frac{(b-a)(7a^2-x^2)}{4(a^2+x^2)^2}+\frac{b}{b^2+x^2}-\frac{a}{a^2+x^2}=\frac{3}{4x}\left(\tan^{-1}\frac{b}{x}-\tan^{-1}\frac{a}{x}\right) \qquad (17)$$

While solving for x appears to be involved, the equation may be handled practically by plotting two curves, one for each side of the equation. Extending the two curves until they intersect will give the solution, the point of intersection being the value of x for which the equality is true. The solution of equation 17 is given in figure 5 where the ratio $\frac{b}{x}$ is plotted against the ratio $\frac{b}{a}$. When b and a are known, $\frac{b}{x}$ may be found from figure 5 and x may be determined from the ratio.

When the top of the fill coincides with the top of the wall the value of a is zero. For this particular case equation 16 for the maximum moment is of no use. It will be seen that for this case the moment approaches infinity as x approaches zero. This is due to the fact that in theory, as the point of application of the force is approached, the finite force is acting upon an infinitely small area. Practically, however, the load P is not concentrated at a point but is distributed over an area. If the area of distribution is assumed to be a 15-inch circle, it is obvious that the value of x cannot be less than the radius of the circle. Accordingly, the minimum value of x was taken as $7\frac{1}{2}$ inches or 0.625 foot.

METHOD OF IMAGES MAY BE USED

Using four concentrated loads of 12,000 pounds each, a value of k equal to 1.3, n equal to $\frac{1}{4}$, and values of x for the maximum moment, the curves of figure 6 were plotted. It will be noted that the distance a has a considerable effect upon the moment, and that for large values of a the moment is greatly reduced.

In dealing with the standard H-loading it may be necessary in some cases to consider the smaller wheel concentrations 14 feet distant from the large wheels. It is unlikely, however, that two trucks headed in the same direction will enter a bridge at the same instant. Assuming that the four wheels shown in figure 4 are rear wheels of trucks, the front wheels of one truck will be on the fill and the front wheels of the other truck will be on the superstructure. Under such conditions the effect of the two front wheels on the fill will usually be very small in comparison with the effect of the four rear wheels which are close to the wall. However, if it is desired to include the effect of all wheels, the rear wheels may be placed at the point for maximum moment and with the trucks in this position a separate computation made for each set of loads. This position of the trucks should give moments sufficiently close to a maximum for design purposes.

When the total moment and the total horizontal force have been computed the height of the center of pressure may be determined by dividing the moment by the force. The ratio of this height to the height of wall, $(b-a)$, was found to vary from approximately 0.53 to 0.96 as the height of wall varies from 2 to 30 feet. Further, this ratio increases when the height of wall increases or when the distance a decreases. It is noted that the location of the center of pressure is not affected by either of the constants k or n.

Some designers may prefer to assume a soil of perfect elasticity and to use the equation based upon the theory of elasticity rather than the constants determined by experiment. In this case the method of images may be applied as explained by Dr. Raymond D. Mindlin.[4] The constant n will drop out or become equal to zero and the constant k which appears in the above equations will become $\frac{3}{\pi}$. By this method the intensity of normal pressure at any point on the wall is simply double that given by the equation for the stress in an elastic, isotropic solid (see p. 167). The force and moment equations 2 to 15, and equation 16 for the maximum, may be used by making this change in the constants. The values obtained for the force and moment will be slightly less than for $k=1.3$, $n=1/4$, when the load is placed at the point for maximum moment.

Assuming a bridge abutment backfilled with gravel, the moment and horizontal force will be computed by the approximate equations. The conditions assumed will be a live load P of 24 kips, $b=20$ feet, $a=1$ foot, $k=1.3$, and $n=1/4$.

The moment, using equation 14, is

$$M=\frac{2}{3}kPx^{1-n}\left[\frac{(b-a)x}{a^2+x^2}-\left(\tan^{-1}\frac{b}{x}-\tan^{-1}\frac{a}{x}\right)\right]$$

From figure 5 for $\frac{b}{a}=20$, $\frac{b}{x}=9.82$.

Then $x=\frac{20}{9.82}=2.03$ feet, the position of the load for maximum moment when $n=1/4$,

$$(2.03)^{1-n}=(2.03)^{3/4}=1.70$$

and

$$\frac{2}{3}kPx^{1-n}=\frac{2}{3}(1.3)24(1.70)=35.4$$

$$M=35.4\left[\frac{19(2.03)}{5.12}-(\tan^{-1}9.82-\tan^{-1}0.492)\right].$$

$$\tan^{-1}9.82-\tan^{-1}0.492=(84°12')-(26°12')=58.0°=0.01745(58.0)=1.01 \text{ radians.}$$

$$M=35.4(7.52-1.01)=230 \text{ foot-kips.}$$

This moment may be determined from figure 6. The value read from the chart should be divided by 2 since a load of 48 kips was used in computing values for the curves.

By equation 13

$$H=\frac{2}{3}kPx^{1-n}x\left[\frac{1}{a^2+x^2}-\frac{1}{b^2+x^2}\right],$$

the horizontal force

$$H=35.4(2.03)\left[\frac{1}{5.12}-\frac{1}{404.1}\right]=71.8(0.1952-0.0025)$$
$$=13.8 \text{ kips.}$$

If an elastic, isotropic backfill material is assumed and the live load effect on the wall is taken into account by using the method of images the only change in the problem will be in the assumed values of the constants. The new values will be $k=\frac{3}{\pi}$ and $n=0$. Again taking $P=24$ kips, $b=20$ ft., and $a=1$ foot, from figure 5 for $\frac{b}{a}=20$, $\frac{b}{x}=6.90$.

Then $x=\frac{20}{6.90}=2.80$ feet, the position of the load for a maximum moment when $n=0$.

$$\frac{2}{3}kPx^{1-n}=\frac{2}{3}\cdot\frac{3}{\pi}(24)2.80=42.8$$

$$M=42.8\left[\frac{19(2.80)}{8.84}-(\tan^{-1}6.90-\tan^{-1}0.357)\right]$$

$$\tan^{-1}6.90-\tan^{-1}0.357=(81°46')-(19°38')$$
$$=62.13°=0.01745(62.13)=1.08 \text{ radians}$$

$$M=42.8(6.02-1.08)=211 \text{ foot-kips}$$

and

$$H=42.8(2.80)\left[\frac{1}{8.84}-\frac{1}{407.8}\right]$$
$$=119.5\ (0.1130-0.0024)=13.2 \text{ kips.}$$

The above computations were made with an ordinary 10-inch slide rule using C, D, L, and T scales.

CONCLUSIONS

In the preparation of figure 6 the value of k was taken as 1.3 as this is the value suggested as safe for gravel material similar to that used in the experiments.[3] In the absence of further experimental data this value might be used for the average gravel backfill.

Regarding the experimental constant n, the value of 1/4 was found to agree most closely with the experimental data reported by Spangler. Since this constant is written as an exponent of x, its value affects the position of the load for maximum moment. With reference to the curves of figure 5 it will be noted that for a maximum moment the load must be placed farther from the wall for n equal to zero than for n equal to ¼.

The reader may question when to use the method involving the empirical constants and when to use the method of images. It is the writer's opinion that when dealing with a backfill whose soil properties are unknown it would be more logical to assume elasticity and use the method of images than to make a guess at a value for k which had not been verified by experiment.

In this study an attempt has been made to shorten the gap between theory and practice by reducing the amount of mathematical work involved in applying the theory. Since the equations derived are in conformity with measured pressure intensities it is believed that by the use of these equations the effect of concentrated loads can be more accurately predicted than by rule of thumb methods.

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[4] Dr. Raymond D. Mindlin. Proceedings of the International Conference on Soil Mechancis and Foundation Engineering. vol. III. 1936, p. 155.

[3] Horizontal Pressures on Retaining Walls Due to Concentrated Surface Loads, by M. G. Spangler. Iowa Engineering Experiment Station Bulletin 140. 1938.

(*Continued from page 166*)

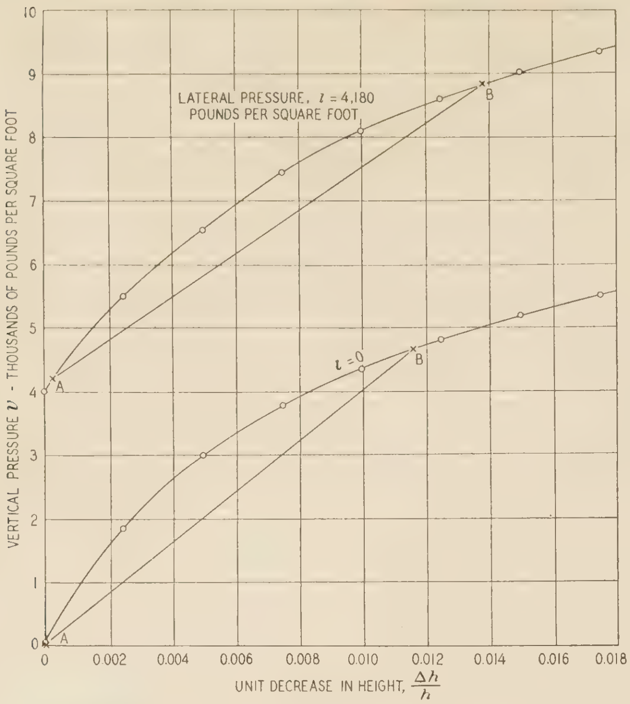

FIGURE 8.—TRIAXIAL TEST DATA FOR FILL SOIL.

lower curve, is $\frac{2,984-0}{0.0235+0.0001}=126,000$ pounds per square foot$=C$. The average modulus C is then taken as $\frac{109,000+126,000}{2}=118,000$ pounds per square foot.

For $\frac{z}{B}=1.97$, $\mu=\frac{1}{2}$ and $\frac{b}{B}=0.453$, it is seen from figure 5 that $F=0.73$. Then, from equation 18, S_L (undersoil)$=\frac{pB}{C}F=\frac{4,662\times 50.8}{118,000}\times 0.73=1.46$ feet.

S_L within the fill itself is now computed and equation 11, taking $K'=0$, is used for this purpose. Assume that the lateral pressure is zero from 0′ to 0, figure 6. This assumption is on the side of safety.

The vertical pressure at 0′ is zero whereas at 0 it is equal to p or 4,662 pounds per square foot as already shown. To be consistent with the procedure followed in computing S_L in the undersoil, it is assumed that the point B on each of the two curves, figure 8, corresponds to $v-l=v-0=4,662$ pounds, the maximum $v-l$ in the fill. Figure 8 shows the v versus $\frac{\Delta h}{h}$ characteristics of the compacted fill soil. For the upper curve, figure 8, C is computed as 343,000 pounds per square foot and for the lower curve its value 398,000 pounds per square foot, the average value being 370,000 pounds per square foot. Substituting in equation 11, S_L(fill)$=\frac{3w}{8C}H^2=\frac{3\times 126}{8\times 370,000}\times 37\times 37=0.18$ foot.

The total settlement due to soil deformation is then S_L(fill)$+S_L$(undersoil)$=0.18+1.46=1.64$ feet.

Due to deformation of soil at constant volume, the elevation of the roadway is therefore diminished by 1.64 feet. A considerable part of this settlement would most likely occur during construction of the embankment. To obtain the total settlement, to the settlement S_L must be added the settlement S_C caused by volume changes in the fill and undersoil.

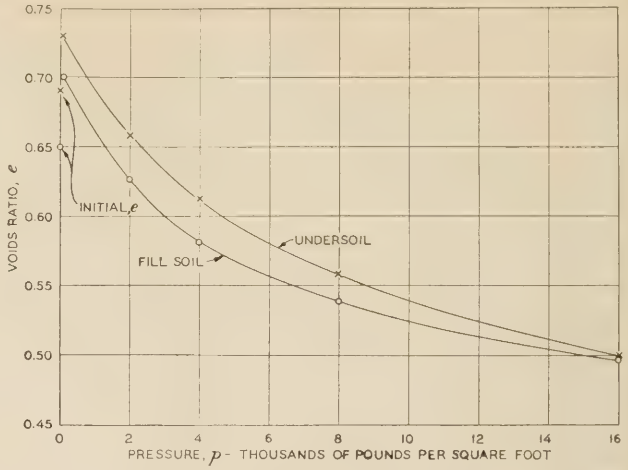

FIGURE 9.—CONSOLIDATION TEST DATA FOR FILL AND FOUNDATION SOILS.

COMPUTATION OF S_C ILLUSTRATED

In figure 9, the voids ratio, e, versus pressure curves are shown for the two soils, fill soil and undersoil. The initial voids ratios of the undisturbed core samples at their natural moisture contents are shown on the e axis in this figure. These are the e values prior to making the consolidation test. For the foundation soil, the initial e is 0.69 and for the fill soil, the initial e is 0.65.

For computing the settlement S_C, the following expression is used,

$$S_C=\frac{e_i-e_f}{1+e_i}\times D \quad \text{-----------------} (19)$$

where e_i is the average voids ratio within the thickness D of the soil mass prior to its consolidation and e_f is the average voids ratio within the same soil mass when consolidation is complete. In this problem, D is the height of fill, 37 feet, when computing S_C within the fill and the thickness of the compressible layer of undersoil, 100 feet, when computing S_C in the undersoil.

For the fill, e_i is taken as the initial value, 0.65, the voids ratio of the soil as compacted in the fill. In computing e_f for the fill, it is assumed that the compacted soil expands at the road surface from $e=0.65$ to $e=0.70$, as shown in figure 9, this expansion being due to wetting. At the base of the fill, the final value of e corresponds to the fill load of 4,662 pounds per square foot and from figure 9, this value of e is 0.57. Then e_f, the average final value of e is $\frac{0.70+0.57}{2}=0.635$. Then S_C (fill)$=$

$$\frac{0.65-0.635}{1+0.65}\times 37=0.34 \text{ foot.}$$

For the undersoil, it is assumed that the clay soil is consolidated under its own weight prior to fill construction. The initial voids ratio of an undisturbed core sample taken at the subgrade surface is seen to be 0.69 from figure 9. At a depth of 100 feet, the vertical pressure due to overburden is 100 × weight per cubic foot of undersoil$=100\times 128=12,800$ pounds per square foot, corresponding to an e of 0.52. Therefore, $e_i=\frac{0.69+0.52}{2}=0.605$, the average e prior to consolidation under the fill load. After complete consolidation under the fill load, e at the point 0, figure 6, corresponds to a pressure of 4,662 pounds per square foot. This value of e, figure 9, is 0.60.

At the bottom of the compressible undersoil layer, point B, figure 6, the final value of e corresponds to a pressure of 12,800 pounds per square foot due to overburden plus the pressure transmitted by the weight of the fill. The latter pressure is the product, pf, where $p=4{,}662$ pounds per square foot and f is obtained from figure 4. To find f, remember that $\frac{b}{B}=0.453$ and $\frac{z}{B}=1.97$ in this problem. Thus $pf=4{,}662\times0.54=2{,}517$ pounds per square foot. Then, the total vertical pressure at the lower boundary of the compressible supporting layer of soil is $12{,}800+2{,}517=15{,}317$ pounds per square foot corresponding to an e of 0.50. Then $e_f=\frac{0.60+0.50}{2}=0.55$, the average e from top to bottom of the supporting soil subsequent to complete consolidation under the weight of the fill. Using equation 19, $S_C\text{ (undersoil)}=\frac{0.605-0.550}{1+0.605}\times100=3.43$ feet.

The total S_C is then $S_C\text{ (fill)}+S_C\text{ (undersoil)}=0.34+3.43=3.77$ feet and total S_L+ total $S_C=1.64+3.77=5.41$ feet.

SETTLEMENT RECORDS OF EMBANKMENTS NEEDED

The purpose of presenting formulas relating to the bearing capacities and displacements of soils is to enable the engineer to make a reasonably accurate approximation. It would be a serious mistake to rely completely on any mathematical formula derived from theory and assumptions without reference to observations in the field and to practical experience. Where the problem deals with large earth masses, mathematical expressions can at the best only indicate the general trend of physical occurrences. After many years, the proposed formulas may be modified and accepted or they may be completely rejected depending upon the extent to which, on trial, they have proved to be serviceable. The details in the development of the formulas serve to establish and clarify certain fundamental principles and conceptions which are often of more value than the formulas themselves.

The theoretical expressions for computing settlement caused by lateral displacement, such as equations 11, 16, and 17 would be expected to be more precise for relatively small deformations. As deformations increase in magnitude one or more points within the soil mass may become stressed to a condition characteristic of failure while the soil surrounding these points is stressed below this limit. As soon as a condition of failure is reached anywhere in the soil mass, even though it be reached at only one point, the whole system of stresses throughout the soil in the loaded region changes and the stress-deformation relations expressed by equations 11, 16, and 17 cannot be considered as a true picture of conditions. However, the true limitations of these theoretical expressions which are based on an assumption of a strictly linear relationship between stress and deformation are not known. With certain soils, the relationship may never be linear for stresses of any magnitude whatsoever.

The essential requirement is a correlation of field observations with theoretical and laboratory studies. Computed settlements such as those presented in the example must be checked against observed settlements. Theory may serve as a rough guide or crude yardstick in promoting more thorough and intelligent field studies. This is about the best that can be expected of its use.

DISPOSITION OF STATE MOTOR-FUEL TAX RECEIPTS, 1939

[Compiled for calendar year from reports of State authorities]

State	Net total receipts of calendar year	Adjustments due to undistributed funds, etc. [1]	Net total funds distributed [2]	Expenses of collection and administration	For other administrative purposes [3]	For State highway purposes						For local roads and streets [6]				For other highway purposes (park and forest roads, etc.)	For nonhighway purposes					
						Construction, maintenance, and administration [4]	State highway police	Service of State highway obligations			Total for State highway purposes	For work on county and local roads [4]	For work on city streets [7]	Service of local highway obligations	Total		To general funds [8]		For relief of unemployment or destitution	For education	For other purposes [9]	Total
								State highway bonds and notes	Reimbursement obligations [5]	Total							Inspection fees, dealers licenses, etc.	Motor-fuel tax				
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Alabama	14, 476	−79	14, 397	34	61	5, 103		2, 070		2, 070	7, 173	7, 129			7, 129							
Arizona	4, 446	78	4, 524	60		2, 989	116				3, 105	*1, 357			1, 357						2	2
Arkansas	10, 742		10, 742	344	3	2, 959	21	4, 288	1, 818	6, 106	9, 086	1, 123		186	1, 309							
California	49, 811	−916	48, 895	184		28, 664					28, 664	*13, 226	3, 914		17, 140				2, 907			2, 907
Colorado	7, 751	32	7, 783	97	24	3, 761	270	1, 555		1, 555	5, 586	2, 076			2, 076							
Connecticut	9, 961	39	10, 000	27		8, 366			1, 607	1, 607	9, 973											
Delaware	2, 146		2, 146	10		[4] 1, 395	201	154	372	526	2, 122	([4])	1		1						13	13
Florida	24, 767	941	25, 708	32	91	12, 795			8, 958	8, 958	21, 753						319	1, 738		1, 737	38	3, 832
Georgia	21, 088	−8	21, 080	350		9, 928			19	19	9, 947	3, 385			3, 385		31	3, 634		3, 733		7, 398
Idaho	4, 464	−134	4, 330	19	3	3, 090	17	1		1	3, 108	1, 200			1, 200							
Illinois	39, 400	20	39, 420	182	237	12, 025					12, 025	6, 839	9, 631	3, 791	20, 261		162		4, 385	2, 168		6, 715
Indiana	24, 318	2	24, 320	106	116	12, 922	643				13, 565	7, 835	1, 453		9, 288		376	869				1, 245
Iowa	14, 033	−60	13, 973	68	60	3, 798			3, 352	3, 352	7, 150	*6, 695			6, 695							
Kansas	10, 179	−32	10, 147	338	108	6, 214	123	228	679	907	7, 244	2, 457			2, 457							
Kentucky	13, 836	−6	13, 830	39		11, 863	244				12, 107	1, 684			1, 684							
Louisiana	17, 463	1, 495	18, 958	37	81			10, 696		10, 696	10, 696							2, 723	2, 760	1, 331	1, 330	8, 144
Maine	5, 718		5, 718	16		3, 279	211	1, 610		1, 610	5, 100	602			602							
Maryland	10, 638		10, 638	36		4, 940		1, 442		1, 442	6, 382	915	2, 692	613	4, 220							
Massachusetts	20, 512	−274	20, 238	50		2, 556	376	[10] 3, 344	5	3, 349	6, 281	9, 483		[10] 1, 789	11, 272	1, 239			[10] 1, 389		7	1, 396
Michigan	29, 794	150	29, 944	260		18, 502		4, 627		4, 627	23, 129	*6, 550			6, 550		5					5
Minnesota	18, 813	−90	18, 723	27	112	12, 070	303				12, 373	*6, 186			6, 186		25					25
Mississippi	11, 309	1	11, 310	103	10	2, 574	175	3, 241		3, 241	5, 990	*4, 713			4, 713	494						
Missouri	12, 234		12, 234	58	52	6, 017	255	5, 725	48	5, 773	12, 045						79					79
Montana	4, 807	−103	4, 704	23	7	3, 702		972		972	4, 674											
Nebraska	11, 585	3	11, 588	121	33	5, 903					5, 903	*3, 430	342		3, 772				1, 759			1, 759
Nevada	1, 359		1, 359	4	23	1, 324			8	8	1, 332											
New Hampshire	3, 508	−1	3, 507	([11])		1, 750	109	879		879	2, 738	640		[12] 129	769							
New Jersey	23, 068	203	23, 271	196		7, 845	296	2, 285		2, 285	10, 426	4, 144		889	5, 033	257		[13] 3, 000	3, 290	580	489	7, 359
New Mexico	4, 320	50	4, 370	95	3	2, 401		1, 871		1, 871	4, 272											
New York [14]	69, 757	265	70, 022	107		7, 959	591	4, 695		4, 695	13, 245	*8, 484	1, 743		10, 227	460		45, 983				45, 983
North Carolina	25, 556	4	25, 560	([15])	102	[4] 17,512		6, 635	283	6, 918	24, 430	([4])					915				113	1, 028
North Dakota	2, 736	−23	2, 713	21	66	1, 840					1, 840	760			760		22	4				26
Ohio	[16] 50,466	−1, 570	48, 896	69		20, 082					20, 082	9, 019	6, 510		15, 529			11, 463		1, 753		13, 216
Oklahoma	14, 495	−283	14, 212	419	137	9, 913					9, 913	*3, 220	373		3, 593		150					150
Oregon	10, 582	−268	10, 314	43		6, 209	246	2, 003	9	2, 012	8, 467	*1, 708	10		1, 718	86						
Pennsylvania	59, 590		59, 590	211		25, 947	2, 520	5, 071		5, 071	33, 538	*10, 680			10, 680	95		14, 861			205	15, 066
Rhode Island [17]	4, 031		4, 031	15		1, 148	127	159		159	1, 434	35			35	40		2, 507				2, 507
South Carolina	12, 516		12, 516	44	30	7, 519		1, 468	1, 056	2, 524	10, 043	*2, 065	158		2, 223		176					176
South Dakota	4, 012	40	4, 052	54	54	3, 410	15	9		9	3, 434	491			491	6	13					13
Tennessee	19, 727	−736	18, 991	306	41	2, 486		6, 432	1, 441	7, 873	10, 359	5, 389			5, 389	22	1, 034				1, 840	2, 874
Texas	45, 208	−63	45, 145	697		20, 058	537		11, 117	11, 117	31, 712	1, 640			1, 640					11, 096		11, 096
Utah	3, 688	51	3, 739	9	9	3, 584	137				3, 721											
Vermont	2, 679		2, 679	3		1, 399		294		294	1, 693	962			962	6					15	15
Virginia	17, 829		17, 829	186	32	[4] 16,649	309		263	263	17, 221	[4] 298	79		377						13	13
Washington	16, 006		16, 006	50		6, 719		[10] 118	52	170	6, 889	*5, 900	1, 806	[10] 362	8, 068				[10] 999			999
West Virginia	10, 423	−14	10, 409	15		[4] 5, 584		4, 810		4, 810	10, 394	([4])										
Wisconsin	20, 438	−3, 746	16, 692	75	167	5, 851			2, 360	2, 360	8, 211	5, 052	712		5, 764	141		2, 334				2, 334
Wyoming	2, 580		2, 580	11		1, 745	51	112		112	1, 908	661			661							
District of Columbia	2, 791	5	2, 796	([18])									2, 789		2, 789		7					7
Total	821, 656	−5, 027	816, 629	5, 251	1, 662	364, 349	7, 893	76, 794	33, 447	110. 241	482, 483	148, 033	32, 213	7, 759	188, 005	2, 846	3, 314	89, 116	17, 489	22, 398	4, 065	136, 382

[1] Amounts distributed during the calendar year often differ from actual collections because of undistributed funds and lag between accounts of collecting and expending agencies.

[2] In many States the proceeds of highway user taxes are placed in a common fund from which a distribution is made. The amounts so distributed have been prorated in proportion to the receipts not otherwise dedicated. See following tables.

[3] Where reported separately from collection expenses, funds allotted for motor-fuel inspection, administration of motor vehicle department, and regulation of motor vehicles are shown in this column.

[4] The following amounts for construction and maintenance of county roads under State control are included in allotments for State highway purposes: Delaware, $279,000; North Carolina, $7,367,000; Virginia, $6,554,000; West Virginia, $2,082,000. In Virginia the 3 counties whose roads are not under State control received $298,000.

[5] Reimbursement to counties and local units of government for amounts spent on roads now on State system.

[6] In States indicated by star (*) law provides that these funds may also be used for service of local highway obligations. Amounts so used not reported separately. In Colorado funds may be used on both State and local roads.

[7] This column shows specific allotments for city streets. Where reported separately, funds allotted for urban extensions of State highway system are included in allotments for State highway purposes.

[8] To State general funds, except as follows: Louisiana, 1 cent of tax to parishes; Wisconsin, payment to towns, cities, and villages in lieu of personal property tax formerly imposed on motor vehicles. Allocations to local general funds may have been used in part for highways, but such amounts not reported.

[9] For the following purposes: Arizona, irrigation engineering expenses; Delaware, State parks, CCC ditching, etc.; Florida, aviation; Louisiana and Massachusetts, harbor improvement; New Jersey, debt service on institutional construction bonds, $268,000, department of commerce and navigation, $166,000, other departments, $55,000; North Carolina, State probation and parole commissions; Pennsylvania, aviation, $171,000, cooperative work other departments, $34,000; Tennessee, debt service on nonhighway bonds; Vermont, debt service on nonhighway portion of flood relief bonds; Virginia, aviation.

[10] Includes debt service charges on emergency relief bond issues, prorated in proportion to use of proceeds for State highways, local roads and streets, and nonhighway purposes.

[11] Paid out of motor-vehicle revenue, $6,000. See following table.

[12] Debt service on highway relief bonds, a State obligation incurred for improvement of local roads.

[13] Originally appropriated for relief but later transferred by legislative action to State general fund.

[14] Appropriations for highway purposes out of State general fund have been credited against payments of motor-fuel tax and motor-vehicle revenues to the general fund and prorated in proportion to net receipts from highway user taxes not otherwise dedicated.

[15] Included in cost of collecting motor-vehicle revenue. See following table.

[16] Tax of $641,000 on nonmotor-vehicle fuels not included.

[17] Expenditures for highway purposes have been credited against payments of motor-fuel tax and motor vehicle revenues to the State general fund and prorated in proportion to net receipts from highway user taxes not otherwise dedicated.

[18] Paid out of general revenue. Amount not reported.

DISPOSITION OF STATE MOTOR-VEHICLE RECEIPTS, 1939

[Compiled for calendar year from reports of State authorities]

State	Net total receipts of calendar year	Adjustments due to undistributed funds, etc.[1]	Net total funds distributed [2]	Expenses of collection and administration [3]	For other administrative purposes [4]	For State highway purposes						For local roads and streets [7]				For other highway purposes (park and forest roads, etc.)	For nonhighway purposes				
						Construction, maintenance, and administration [5]	State highway police	Service of State highway obligations			Total for State highway purposes	For work on county and local roads [5]	For work on city streets[8]	Service of local highway obligations	Total		To general funds [9]	For relief of unemployment or destitution	For education	For other purposes [10]	Total
								State highway bonds and notes	Reimbursement obligations [6]	Total											
	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars	1,000 dollars
Alabama	4,947	−10	4,937	434		1,940	632	978		978	3,550		180		180		773				773
Arizona	1,134	−3	1,131	255		843	33				876										
Arkansas	3,140	673	3,813	105		1,096	174	1,640	759	2,399	3,669			39	39						
California	24,646	−172	24,474	3,090	307	3,760	2,889	3,785		3,785	10,434	*3,781			3,781		6,862				6,862
Colorado	2,879	1	2,880	730		750	53	303		303	1,106	1,044			1,044						
Connecticut	6,738	85	6,823	857		2,289	286		440	440	3,015	2,951			2,951						
Delaware	1,313	−512	801	106		[5] 453	66	50	121	171	690	([5])	1		1					4	4
Florida	7,096		7,096	524	217		191				191								6,164		6,164
Georgia	2,620	−153	2,467	300		880	526				1,406	694			694		67				67
Idaho	1,399	−33	1,366	89		114	134				248	*1,029			1,029						
Illinois	24,352	857	25,209	1,336	369	11,294	1,500	9,510		9,510	22,304	1,047			1,047		153				153
Indiana	10,001	242	10,243	1,053		5,006	249				5,255	3,035	563		3,598		337				337
Iowa	12,624	1	12,625	1,442		5,541			4,890	4,890	10,431	752			752						
Kansas	4,363	−180	4,183	602		2,293	46	84	251	335	2,674	907			907						
Kentucky	4,960	1	4,961	485	26	2,021	56				2,077	886			886		1,487				1,487
Louisiana	5,309	−201	5,108	163	50	4,022	435	438		438	4,895										
Maine	3,788	−169	3,619	160		1,990	128	976		976	3,094	365			365						
Maryland	5,538	1	5,539	341	54	2,106	399	1,143		1,143	3,648		852		852		244	400			644
Massachusetts	7,028	251	7,279	1,587	70	712	104	[11] 931	2	933	1,749	2,641		[11] 498	3,139	345		[11] 387		2	389
Michigan	22,119	−182	21,937	957	408		494				494	*19,932			19,932		146				146
Minnesota	9,884	−116	9,768	573		4,573	115	2,338	2,031	4,369	9,057						138				138
Mississippi	2,567		2,567	175		230					230	*2,162			2,162						
Missouri	10,226	−9	10,217	615		5,423	230	3,905	44	3,949	9,602										
Montana	1,634	−52	1,582	79			251				251	1,211	41		1,252						
Nebraska	2,683	−167	2,516	214	18	672	74				746	1,538			1,538						
Nevada	286		286	32		150	20	84		84	254										
New Hampshire	2,962	28	2,990	132	6	1,871	156	3		3	2,030	684		[12] 138	822						
New Jersey	21,312	182	21,494	2,049		7,598	287	2,214		2,214	10,099	4,014		861	4,875	248		3,187	562	474	4,223
New Mexico	1,909	−222	1,687	151	119	576	108				684	184	58		242		491				491
New York [13]	48,432	−38	48,394	2,509	149	10,276	764	6,062		6,062	17,102	*9,072	4,581		13,653	594	14,387				14,387
North Carolina	8,163	−213	7,950	492		[5] 4,976	517	1,885	80	1,965	7,458	([5])									
North Dakota	1,619	−18	1,601	128		747	77				824	649			649						
Ohio	28,625	1,556	30,181	2,780		7,375	825				8,200	*14,177	4,719		18,896					305	305
Oklahoma	6,046	−155	5,891	782	121	1,310	621				1,931	*2,402	655		3,057						
Oregon	3,469	−15	3,454	471		1,804	71	582	2	584	2,459	*496	3		499	25					
Pennsylvania	36,563	[14] −19,215	17,348	1,664		10,987	1,068	2,147		2,147	14,202	1,355			1,355	40				87	87
Rhode Island [15]	2,929	−4	2,925	215		774	86	107		107	967	24			24	27	1,692				1,692
South Carolina	1,915		1,915	170		1,024	369	183	144	327	1,720	3	22		25						
South Dakota	2,165	24	2,189	87		336	1	1		1	338	1,298			1,298	1	465				465
Tennessee	5,443	−262	5,181	850		3,305	221				3,526	77			77	14	714				714
Texas	21,194	64	21,258	1,434		7,138	191				7,329	*12,495			12,495						
Utah	1,176	36	1,212	132	14	9		208		208	217	560	240		800		49				49
Vermont	2,490		2,490	64		1,207	116	254		254	1,577	830			830	5				14	14
Virginia	6,847	78	6,925	334		6,191	190		162	162	6,543		48		48						
Washington	4,560	31	4,591	398		2,567	1,476				4,043	12			12	138					
West Virginia	5,974		5,974	206		[5] 2,792	31	2,945		2,945	5,768	([5])									
Wisconsin	12,954	−2,537	10,417	728	24	3,436			1,386	1,386	4,822	2,967	418		3,385	84	1,374				1,374
Wyoming	622	37	659	13		436	13	197		197	646										
District of Columbia	1,851		1,851	136	55								1,660		1,660						
Total	412,494	−20,490	392,004	32,229	2,007	134,893	16,273	42,953	10,312	53,265	204,431	95,274	14,041	1,536	110,851	1,521	29,379	3,974	6,726	886	40,965

[1] Amounts distributed during the calendar year often differ from actual collections because of undistributed funds and lag between accounts of collecting and expending agencies.

[2] In many States the proceeds of highway user taxes are placed in a common fund from which a distribution is made. The amounts so distributed have been prorated in proportion to the receipts not otherwise dedicated. See preceding and following tables.

[3] Collection expenses in many States include service charges deducted by county and local collectors.

[4] Where reported separately from collection expenses, funds allotted for collection of motor-fuel tax, payments to auto theft fund, and miscellaneous expenses of motor-vehicle regulation are shown in this column.

[5] The following amounts for construction and maintenance of county roads under State control are included in allotments for State highway purposes: Delaware, $91,000; North Carolina, $2,093,000; West Virginia, $648,000.

[6] Reimbursement to counties and local units of government for amounts spent on roads now on State system.

[7] In States indicated by star (*) law provides that these funds may also be used for service of local highway obligations. Amounts so used not reported separately. In Colorado funds may be used on both State and local roads.

[8] This column shows specific allotments for city streets. Where reported separately, funds allotted for urban extensions of State highway system are included in allotments for State highway purposes.

[9] To State general funds except in the following States: Alabama, county and municipal general funds; California, general funds of counties and cities, $3,776,000; New Mexico, county general funds, $307,000; Wisconsin, towns, cities, and villages in lieu of personal property taxes formerly imposed on motor vehicles, $1,370,000. Allocations to county and local general funds may have been used in part for highways, but such amounts not reported.

[10] For the following purposes: Delaware, State parks, CCC ditching, etc.; Massachusetts, harbor improvement; New Jersey, debt service on institutional construction bonds, $259,000, Department of Commerce and Navigation, $162,000, other departments, $53,000; Ohio, care of indigent persons injured in motor-vehicle accidents; Pennsylvania, aviation, $73,000, cooperative work other departments, $14,000; Vermont, debt service on nonhighway portion of flood relief bonds.

[11] Includes debt service charges on emergency relief bond issues, prorated in proportion to use of proceeds for State highways, local roads and streets, and nonhighway purposes.

[12] Debt service on highway relief bonds, a State obligation incurred for improvement of local roads.

[13] Appropriations for highway purposes out of State general fund have been credited against payments of motor-fuel tax and motor-vehicle revenues to the general fund and prorated in proportion to net receipts from highway user taxes not otherwise dedicated.

[14] Due to change in registration year from Jan. 1 to Apr. 1.

[15] Expenditures for highway purposes have been credited against payments of motor-fuel tax and motor-vehicle revenues to the State General Fund and prorated in proportion to net receipts from highway user taxes not otherwise dedicated.

DISPOSITION OF STATE MOTOR-CARRIER TAX RECEIPTS, 1939

[Compiled for calendar year from reports of State authorities]

State	Net total receipts of calendar year	Adjustments due to undistributed funds, etc.[1]	Net total funds distributed [2]	Expenses of collection and administration	For State highway purposes						For local roads and streets [5]				For other highway purposes (park and forest roads, etc.)	For nonhighway purposes		
					Construction, maintenance, and administration [3]	State highway police	Service of State highway obligations			Total for State highway purposes	For work on county and local roads [3]	For work on city streets [6]	Service of local highway obligations	Total		To general funds	For education	Total
							State highway bonds and notes	Reimbursement obligations [4]	Total									
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Alabama	252	−59	193	44	149					149								
Arizona	187	−1	186	37	143	6				149								
Arkansas	3		3	2	1					1								
California	3,032	−8	3,024	421	78					78	5			5		2,520		2,520
Colorado	728	30	758	127	253	18	105		105	376	255			255				
Connecticut	274	−8	266	14	107			21	21	128	124			124				
Delaware	(7)																	
Florida	337	14	351	73								10	262	272			6	6
Georgia	86	−19	67	57	3					3						7		7
Idaho	60	−9	51	21		30				30								
Illinois	(7)																	
Indiana	1,222	86	1,308	106	655	33				688	397	73		470		44		44
Iowa	558		558	166							*392			392				
Kansas	1,313		1,313	321	636	12	23	70	93	741	251			251				
Kentucky	293		293	53	207	4				211	29			29				
Louisiana	93		93	20												73		73
Maine	18		18	18														
Maryland	(8)																	
Massachusetts	140		140	45												95		95
Michigan	465	37	502	210	292					292								
Minnesota	41		41	41														
Mississippi	116		116	34							*82			82				
Missouri	794	144	938	99	694	29		6	6	729	26	84		110				
Montana	61	−6	55	55														
Nebraska	28		28	28														
Nevada	223	2	225	12	189	24				213								
New Hampshire	3		3	3														
New Jersey	100	−6	94		94					94								
New Mexico	193	−73	120	48	72					72								
New York	(7)																	
North Carolina	365		365	12	[3] 253		96	4	100	353	(3)							
North Dakota	36		36	36														
Ohio	522	76	598	119	297					297	182			182				
Oklahoma	1,502	8	1,510	130	716					716	664			664				
Oregon	1,219	−17	1,202	191	592	55	191	1	192	839	*163	1		164	8			
Pennsylvania	8		8		8					8								
Rhode Island	11		11	7	1					1						3		3
South Carolina	256	1	257	68	167					167		22		22				
South Dakota	453	162	615	32	558	2	1		1	561					1	21		21
Tennessee	184	20	204	42	103					103	5			5	1	53		53
Texas	115		115	104	11					11								
Utah	(9)	1	1	1														
Vermont	(7)																	
Virginia	330		330	62	252	8		6	6	266		2		2				
Washington	195		195	195														
West Virginia	103		103		43		60		60	103								
Wisconsin	1,675	−152	1,523	251												1,272		1,272
Wyoming	248	5	253	24	223	6				229								
District of Columbia	213		213													213		213
Total	18,055	228	18,283	3,329	6,797	227	476	108	584	7,608	2,575	192	262	3,029	10	4,301	6	4,307

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[1] Amounts distributed during the calendar year often differ from actual collections because of undistributed funds and lag between accounts of collecting and expending agencies.

[2] In many States the proceeds of highway user taxes are placed in a common fund from which a distribution is made. The amounts so distributed have been prorated in proportion to the receipts not otherwise dedicated. See preceding tables

[3] Approximately $106,000 for use on county roads under state control in North Carolina included in allotments for State highway purposes.

[4] Reimbursement to counties and local units of government for amounts spent on roads now on State system.

[5] In States indicated by star (*) law provides that these funds may also be used for service of local highway obligations. Amounts so used not reported separately. In Colorado funds may be used on both State and local roads.

[6] This column shows specific allotments for city streets. Where reported separately, funds allotted for urban extensions of State highway system are included in allotments for State highway purposes.

[7] No special taxes on motor carriers reported.

[8] Ton-mile and passenger-mile taxes paid by motor carriers in lieu of registration fees included in motor-vehicle receipts, preceding table.

[9] Motor-carrier taxes no longer imposed in Utah.

DISPOSITION OF RECEIPTS FROM STATE IMPOSTS ON HIGHWAY USERS, 1939

[Compiled for calendar year from reports of State authorities]

State	Net total receipts of calendar year[1]	Adjustments due to undistributed funds, etc.[2]	Net total funds distributed	Expenses of collection and administration[3]	For State highway purposes						For local roads and streets[6]				For other highway purposes (park and forest roads, etc.)	For nonhighway purposes					
							Service of State highway obligations									To general funds[8]					
					Construction, maintenance, and administration[4]	State highway police	State highway bonds and notes	Reimbursement obligations[5]	Total	Total for State highway purposes	For work on county and local roads[4]	For work on city streets[7]	Service of local highway obligations	Total		Motor-fuel inspection fees, dealers licenses, etc.	All other highway user imposts	For relief of unemployment or destitution	For education	For other purposes[9]	Total
	1,000 dollars	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*	*1,000 dollars*
Alabama	19,675	−148	19,527	573	7,192	632	3,048		3,048	10,872	7,129	180		7,309			773				773
Arizona	5,767	74	5,841	352	3,975	155				4,130	*1,357			1,357						2	2
Arkansas	13,885	673	14,558	454	4,056	195	5,928	2,577	8,505	12,756	1,123		225	1,348							
California	77,489	−1,096	76,393	4,002	32,502	2,889	3,785		3,785	39,176	*17,012	3,914		20,926			9,382	2,907			12,289
Colorado	11,358	63	11,421	978	4,764	341	1,963		1,963	7,068	3,375			3,375							
Connecticut	16,973	116	17,089	898	10,762	286		2,068	2,068	13,116	3,075			3,075							
Delaware	3,459	−512	2,947	116	[4] 1,848	267	204	493	697	2,812	(4)	2		2						17	17
Florida	32,200	955	33,155	937	12,795	191		8,958	8,958	21,944		10	262	272		319	1,738		7,907	38	10,002
Georgia	23,794	−180	23,614	707	10,811	526		19	19	11,356	4,079			4,079		31	3,708		3,733		7,472
Idaho	5,923	−176	5,747	132	3,204	181	1		1	3,386	*2,229			2,229							
Illinois	63,752	877	64,629	2,124	23,319	1,500	9,510		9,510	34,329	7,886	9,631	3,791	21,308		162	153	4,385	2,168		6,868
Indiana	35,541	330	35,871	1,381	18,583	925				19,508	11,267	2,089		13,356		376	1,250				1,626
Iowa	27,215	−59	27,156	1,736	9,339			8,242	8,242	17,581	*7,839			7,839							
Kansas	15,855	−212	15,643	1,369	9,143	181	335	1,000	1,335	10,659	3,615			3,615							
Kentucky	19,089	−5	19,084	603	14,091	304				14,395	2,599			2,599			1,487				1,487
Louisiana	22,865	1,294	24,159	351	4,022	435	11,134		11,134	15,591							2,796	2,760	1,331	1,330	8,217
Maine	9,524	−169	9,355	194	5,269	339	2,586		2,586	8,194	967			967							
Maryland	16,176	1	16,177	431	7,046	399	2,585		2,585	10,030	915	3,544	613	5,072			244	400			644
Massachusetts	27,680	−23	27,657	1,752	3,268	480	[10] 4,275	7	4,282	8,030	12,124		[10] 2,287	14,411	1,584		95	[10] 1,776		9	1,880
Michigan	52,378	5	52,383	1,835	18,794	494	4,627		4,627	23,915	*26,482			26,482		5	146				151
Minnesota	28,738	−206	28,532	753	16,643	418	2,338	2,031	4,369	21,430	*6,186			6,186		25	138				163
Mississippi	13,992	1	13,993	322	2,804	175	3,241		3,241	6,220	*6,957			6,957	494						
Missouri	23,254	135	23,389	824	12,134	514	9,630	98	9,728	22,376	26	84		110		79					79
Montana	6,502	−161	6,341	164	3,702	251	972		972	4,925	1,211	41		1,252							
Nebraska	14,296	−164	14,132	414	6,575	74				6,649	*4,968	342		5,310				1,759			1,759
Nevada	1,868	2	1,870	71	1,663	44	84	8	92	1,799											
New Hampshire	6,473	27	6,500	141	3,621	265	882		882	4,768	1,324		[11] 267	1,591							
New Jersey	44,480	379	44,859	2,245	15,537	583	4,499		4,499	20,619	8,158		1,750	9,908	505		[12] 3,000	6,477	1,142	963	11,582
New Mexico	6,422	−245	6,177	416	3,049	108	1,871		1,871	5,028	184	58		242			491				491
New York [13]	118,189	227	118,416	2,765	18,235	1,355	10,757		10,757	30,347	*17,556	6,324		23,880	1,054		60,370				60,370
North Carolina	34,084	−209	33,875	606	[4] 22,741	517	8,616	367	8,983	32,241	(4)					915				113	1,028
North Dakota	4,391	−41	4,350	251	2,587	77				2,664	1,409			1,409		22	4				26
Ohio	79,613	62	79,675	2,968	27,754	825				28,579	*23,378	11,229		34,607			11,463		1,753	305	13,521
Oklahoma	22,043	−430	21,613	1,589	11,939	621				12,560	*6,286	1,028		7,314		150					150
Oregon	15,270	−300	14,970	705	8,605	372	2,776	12	2,788	11,765	*2,367	14		2,381	119						
Pennsylvania	96,161	[14] −19,215	76,946	1,875	36,942	3,588	7,218		7,218	47,748	*12,035			12,035	135		14,861			292	15,153
Rhode Island [15]	6,971	−4	6,967	237	1,923	213	266		266	2,402	59			59	67		4,202				4,202
South Carolina	14,687	1	14,688	312	8,710	369	1,651	1,200	2,851	11,930	*2,068	202		2,270		176					176
South Dakota	6,630	226	6,856	227	4,304	18	11		11	4,333	1,789			1,789	8	13	486				499
Tennessee	25,354	−978	24,376	1,239	5,894	221	6,432	1,441	7,873	13,988	5,471			5,471	37	1,034	767			1,840	3,641
Texas	66,517	1	66,518	2,235	27,207	728		11,117	11,117	39,052	*14,135			14,135					11,096		11,096
Utah	4,864	88	4,952	165	3,593	137	208		208	3,938	560	240		800			49				49
Vermont	5,169		5,169	67	2,606	116	548		548	3,270	1,792			1,792	11					29	29
Virginia	25,006	78	25,084	614	[4] 23,092	507		431	431	24,030	[4] 298	129		427						13	13
Washington	20,761	31	20,792	643	9,286	1,476	[10] 118	52	170	10,932	*5,912	1,806	[10] 362	8,080	138			[10] 999			999
West Virginia	16,500	−14	16,486	221	[4] 8,419	31	7,815		7,815	16,265	(4)										
Wisconsin	35,067	−6,435	28,632	1,245	9,287			3,746	3,746	13,033	8,019	1,130		9,149	225		4,980				4,980
Wyoming	3,450	42	3,492	48	2,404	70	309		309	2,783	661			661							
District of Columbia	4,855	5	4,860	191								4,449		4,449		7	213				220
Total	1,252,205	−25,289	1,226,916	44,478	506,039	24,393	120,223	43,867	164,090	694,522	245,882	46,446	9,557	301,885	4,377	3,314	122,796	21,463	29,130	4,951	181,654

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[1] Includes receipts from motor-fuel taxes, motor-vehicle fees and fines, and special imposts on motor vehicles operated for hire (motor-carrier taxes). See preceding tables, which give distribution of receipts separately.

[2] Amounts distributed during the calendar year often differ from actual collections because of undistributed funds and lag between accounts of collecting and expending agencies.

[3] Includes expenses of collection and administration of motor-fuel tax, motor-vehicle fees, and motor-carrier taxes, and miscellaneous expenses of motor-vehicle regulation.

[4] The following amounts for construction and maintenance of county roads under State control are included in allotments for State highway purposes: Delaware, $370,000; North Carolina, $9,566,000; Virginia, $6,554,000; West Virginia, $2,730,000. In Virginia, the 3 counties whose roads are not under State control received $298,000 from the State motor-fuel tax.

[5] Reimbursement to counties and local units of government for amounts spent on roads now on State system.

[6] In States indicated by star (*) law provides that these funds may also be used for service of local highway obligations. Amounts so used not reported separately. In Colorado funds may be used on both State and local roads.

[7] This column shows specific allotments for city streets. Where reported separately, funds allotted for urban extensions of State highway system are included in allotments for State highway purposes.

[8] To State general funds except in the following States: Alabama, county and municipal general funds; California, general funds of counties and cities, $3,776,000; Louisiana, parish general funds, $2,723,000; New Mexico, county general funds, $307,000; Wisconsin, towns, cities, and villages in lieu of personal property tax formerly imposed on motor vehicles, $3,704,000. Allocations to local general funds may have been used in part for highways, but such amounts not reported.

[9] For the following purposes: Arizona, irrigation engineering expenses; Delaware, State parks, C. C. C. ditching, etc.; Florida, aviation; Louisiana and Massachusetts, harbor improvement; New Jersey, debt service on institutional construction bonds, $527,000, department of commerce and navigation, $328,000, other departments, $108,000; North Carolina, State probation and parole commissions; Ohio, care of indigent persons injured in motor-vehicle accidents; Pennsylvania, aviation, $244,000, cooperative work other departments, $48,000; Tennessee, debt service on nonhighway bonds; Vermont, debt service on nonhighway portion of flood relief bonds; Virginia, aviation.

[10] Includes debt service charges on emergency relief bond issues, prorated in proportion to use of proceeds for State highways, local roads and streets, and nonhighway purposes.

[11] Debt service on highway relief bonds, a State obligation incurred for improvement of local roads.

[12] Originally appropriated for relief, but later transferred by legislative action to State general fund.

[13] Appropriations for highway purposes out of State general fund have been credited against payments of motor-fuel tax and motor-vehicle revenues to the general fund and prorated in proportion to net receipts from highway user taxes not otherwise dedicated.

[14] Due to change in registration year from January 1 to April 1.

[15] Expenditures for highway purposes have been credited against payments of motor-fuel tax and motor-vehicle revenues to the State general fund and prorated in proportion to net receipts from highway-user taxes not otherwise dedicated.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF OCTOBER 31, 1940

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	$ 1,761,824	$ 876,167	49.3	$ 5,845,388	$ 2,906,953	220.1	$ 1,187,040	$ 590,890	47.5	$ 1,871,145
Arizona	1,026,203	680,107	47.7	887,592	565,761	51.3	717,770	357,416	16.6	1,008,472
Arkansas	3,523,529	1,629,159	76.7	1,785,607	886,895	78.0	467,546	233,127	26.1	288,879
California	3,584,812	1,876,157	70.2	8,014,486	4,136,279	113.4	2,609,316	1,415,170	56.4	1,347,487
Colorado	1,676,370	923,229	127.7	2,245,258	1,265,427	112.3	255,540	144,023	69.0	2,026,469
Connecticut	590,590	293,455	5.4	2,274,635	1,101,846	19.1	258,052	125,674	3.0	988,696
Delaware	95,119	47,559	2.9	1,927,523	962,982	29.6	155,407	51,044		1,048,125
Florida	943,913	471,956	25.7	3,020,271	1,499,856	91.2	840,971	420,485	17.4	2,313,581
Georgia	1,790,959	887,744	111.7	7,861,815	3,931,408	311.4	2,387,793	1,193,896	118.8	4,666,842
Idaho	1,203,714	739,131	120.2	925,031	568,325	65.1	534,222	266,364	27.2	1,345,450
Illinois	3,838,419	1,896,919	84.5	8,094,016	4,046,843	165.6	2,887,476	1,218,238	93.6	2,132,561
Indiana	2,389,929	1,191,906	61.1	7,654,685	3,677,186	129.9	2,195,394	1,065,542	32.8	890,064
Iowa	3,086,933	1,396,940	100.5	4,919,428	2,251,662	168.2	2,080,631	977,816	69.5	164,273
Kansas	2,079,065	1,038,203	152.2	6,454,040	3,225,946	427.2	2,981,227	1,490,612	181.2	2,973,201
Kentucky	1,785,343	888,277	35.0	3,487,071	1,743,535	107.4	576,781	288,390	38.0	2,907,597
Louisiana	643,730	316,311	5.4	12,506,169	3,302,037	64.7	1,377,511	681,067	37.7	2,869,293
Maine	1,003,748	496,030	20.3	1,025,511	512,755	29.3	18,200	9,100	.6	620,911
Maryland	575,000	287,500	10.2	3,463,558	1,723,362	40.1	489,303	244,651	5.1	1,233,790
Massachusetts	986,611	492,229	9.9	3,102,023	1,543,536	26.1	4,950	2,475		2,990,700
Michigan	2,363,181	1,126,875	84.2	11,128,168	5,465,734	305.7	1,053,463	471,732	35.4	284,629
Minnesota	3,256,423	1,572,971	289.3	6,599,256	3,292,517	392.4	577,421	288,711	27.1	3,135,632
Mississippi	1,231,532	508,478	43.3	6,646,274	3,006,631	333.6	2,026,160	990,330	119.7	1,295,200
Missouri	2,498,269	1,249,062	130.4	7,608,884	3,476,421	194.2	3,576,503	1,319,892	119.4	3,518,941
Montana	3,789,198	2,145,589	255.7	2,104,985	1,187,884	129.5	644,474	363,677	29.5	3,152,825
Nebraska	2,914,534	1,452,684	331.6	5,247,037	2,540,265	621.9	1,686,449	843,224	180.7	2,013,243
Nevada	1,404,260	1,208,281	74.6	1,166,186	1,015,652	48.5	9,615	8,381	.2	756,831
New Hampshire	642,060	314,046	18.4	1,220,387	599,658	27.1				904,734
New Jersey	1,126,220	562,820	8.9	4,595,830	2,297,915	32.9	1,047,230	523,615	5.5	1,610,075
New Mexico	1,327,401	817,541	123.7	1,827,559	1,109,792	92.7	343,273	206,925	7.1	970,729
New York	4,332,626	2,133,608	88.7	16,837,591	8,172,935	224.4	2,248,227	989,209	31.2	328,817
North Carolina	3,327,539	1,662,772	165.4	4,814,917	2,407,375	232.2	765,020	366,115	27.9	1,328,590
North Dakota	1,322,620	719,223	134.4	3,079,856	1,704,036	245.7	2,483,624	1,261,570	201.6	3,215,741
Ohio	1,805,773	902,886	23.8	13,736,202	6,843,772	126.5	4,005,118	2,001,379	32.8	3,709,535
Oklahoma	1,496,092	793,964	72.4	3,340,533	1,764,846	106.3	1,063,885	511,530	42.6	4,015,103
Oregon	2,668,746	1,592,001	135.0	1,962,173	1,175,844	40.6	1,328,524	613,810	36.8	625,580
Pennsylvania	2,894,188	1,419,755	40.7	12,775,559	6,344,434	117.9	2,636,166	1,305,860	25.8	2,099,685
Rhode Island	573,613	286,190	4.7	1,190,347	594,172	12.9	497,325	248,330	3.6	747,071
South Carolina	805,047	385,103	46.5	2,319,020	1,118,158	166.5	933,689	416,210	69.6	2,150,306
South Dakota	2,174,510	1,217,052	330.5	4,298,190	2,598,660	600.3	1,234,280	774,350	178.0	2,057,833
Tennessee	1,487,471	738,520	32.4	3,767,502	1,883,751	130.9	523,998	261,999	16.8	3,690,328
Texas	6,014,902	2,967,937	383.1	6,903,032	3,425,362	308.3	3,914,199	1,854,235	163.8	5,163,273
Utah	797,848	581,181	58.8	904,910	677,622	46.8	630,615	240,560	14.9	735,206
Vermont	648,589	324,295	23.3	1,119,784	558,005	29.2	250,623	125,312	5.0	272,018
Virginia	1,588,149	747,427	48.7	3,909,259	1,882,228	73.9	809,254	402,834	17.2	1,072,621
Washington	2,250,340	1,184,481	43.7	3,060,584	1,622,135	62.2	52,315	27,900	1.2	799,736
West Virginia	1,304,780	648,925	38.1	3,068,345	1,527,971	88.6	419,199	209,600	10.2	1,628,167
Wisconsin	3,602,500	1,753,281	112.9	3,567,914	1,771,735	153.9	436,907	212,894	13.1	3,240,854
Wyoming	1,378,588	868,610	162.3	945,228	600,017	95.1	487,651	311,701	58.8	667,543
District of Columbia	224,000	112,000	1.6	314,242	157,121	2.9	250,100	117,016	1.5	337,231
Hawaii	95,573	44,205	1.7	605,628	304,762	8.9	228,633	114,161	3.9	1,498,907
Puerto Rico	20,338	9,980	.2	1,704,384	843,290	27.9				717,500
TOTALS	93,952,721	48,480,722	4,425.6	227,863,873	111,823,294	7,330.4	58,189,070	28,159,042	2,321.4	91,432,020

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF OCTOBER 31, 1940

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	$ 175,144	$ 87,363	9.4	$ 1,276,990	$ 635,975	60.7	$ 37,167	$ 18,583		$ 358,928
Arizona	97,773	49,619	10.5	249,237	179,933	8.1				231,780
Arkansas	358,381	158,811	14.6	306,339	152,958	20.6	105,323	70,125	12.2	35,478
California	502,722	275,750	22.3	600,819	322,833	19.8	165,660	88,200	2.2	739,438
Colorado				258,151	122,631	4.9	51,494	29,022	2.1	138,569
Connecticut	199,876	98,121	2.0	275,614	131,200	4.4				165,242
Delaware	69,537	34,768	7.8	98,995	41,350	7.7				268,125
Florida	12,030	6,015		509,329	254,665	3.2	398,579	173,817	17.0	194,942
Georgia	53,282	26,106	8.3	763,874	366,937	64.0	438,698	219,349	43.5	1,001,758
Idaho	98,027	60,463	17.0	190,312	114,011	10.7	40,748	24,382	3.0	104,989
Illinois	1,269,585	632,618	67.7	1,208,200	589,100	36.2	327,600	147,500	14.1	161,709
Indiana	410,671	200,658	29.1	128,482	64,241	5.6	225,336	112,600	12.2	855,868
Iowa	1,778,339	846,670	353.6	783,453	371,896	191.3	500,830	235,853	160.4	88,647
Kansas	234,574	117,287	29.6	773,916	389,866	50.7	427,439	213,719	28.1	1,109,944
Kentucky	539,652	162,935	40.9	606,853	200,095	35.0	475,019	125,751	21.3	254,327
Louisiana	41,637	20,818	3.7	256,292	128,091	22.0				458,796
Maine	213,162	101,890	12.1	126,296	61,048	6.4				5,551
Maryland	45,300	22,650	1.1	136,390	68,195	7.1	86,000	42,500	6.1	383,032
Massachusetts	123,647	61,177	2.8	508,159	252,095	10.7	37,950	18,975	.4	479,637
Michigan	867,931	425,758	61.9	854,040	427,020	76.4	536,960	268,480	41.3	339,469
Minnesota	234,436	113,490	31.1	1,021,515	510,041	154.9	425,943	212,972	55.2	761,519
Mississippi	172,962	86,481	10.6	846,952	417,976	41.9	209,800	93,365	9.3	436,082
Missouri	381,414	190,305	55.6	416,637	195,566	41.2	356,812	141,812	37.7	633,688
Montana	606,308	342,715	78.7	117,816	66,483	5.3				647,944
Nebraska	336,160	167,619	63.6	684,169	336,101	89.3	142,915	71,457	28.4	216,967
Nevada	176,020	147,191	37.1	136,697	118,675	11.4	80,414	60,944	6.8	6,976
New Hampshire	85,641	40,146	2.2	60,190	29,832	1.2				167,812
New Jersey	319,500	159,750	10.6	318,057	158,940	11.4				503,134
New Mexico	101,564	63,386	13.1	634,137	343,277	28.8				86,993
New York	1,067,601	533,801	43.9	2,202,315	1,057,353	55.6	118,500	42,000	7.0	76,719
North Carolina	597,005	298,369	58.6	501,453	251,693	39.0	59,190	29,595	5.8	298,943
North Dakota	42,880	24,583	.3	141,704	75,952	1.2	27,520	14,750	2.4	1,014,689
Ohio	510,397	255,133	18.6	2,712,130	1,354,805	87.8	403,280	201,640	17.0	676,153
Oklahoma	581,887	308,724	43.8	209,265	110,288	13.3	92,880	49,059	3.1	931,680
Oregon	330,679	179,276	53.4	247,084	103,394	16.4	162,564	75,990	13.5	181,443
Pennsylvania	877,923	431,438	33.8	1,446,009	722,096	36.1	128,000	64,000	1.9	211,587
Rhode Island	150,728	75,309	3.4	89,358	44,679	.2	88,661	44,265	.9	45,797
South Carolina	149,900	61,994	12.3	614,103	233,873	80.6	284,667	91,000	41.3	167,095
South Dakota				3,624	3,624		24,600	13,780	9.0	1,267,133
Tennessee	109,151	52,519	7.9	223,822	111,911	10.1	101,734	50,867	2.8	865,132
Texas	1,095,726	536,563	166.2	729,528	360,278	56.4	505,300	234,785	47.4	708,420
Utah	25,247	16,100	6.2	245,282	156,660	25.4				124,932
Vermont	255,700	86,334	9.5	250,608	65,721	10.0	42,494	21,247	1.2	1,253
Virginia	301,000	139,038	17.4	438,182	199,955	17.9	213,302	101,655	9.8	184,705
Washington	200,724	105,688	9.5	422,281	223,839	21.5	234,587	121,700	25.0	142,634
West Virginia	262,400	130,675	15.2	74,819	37,409	3.4	127,225	63,612	4.5	409,548
Wisconsin	236,054	117,114	3.3	698,927	349,360	26.6	79,661	35,800	1.7	615,766
Wyoming	433,925	258,391	42.8	73,067	43,669	4.0	73,555	47,016	5.1	70,147
District of Columbia	38,300	19,150	.6	92,384	45,692	.8				22,150
Hawaii	277,851	138,782	8.6	1,096	1,096					158,778
Puerto Rico				302,225	147,640	14.0	55,188	27,140	2.1	80,408
TOTALS	17,050,353	8,469,541	1,552.3	25,867,177	12,752,018	1,551.2	7,893,595	3,699,307	702.8	19,092,456

U. S. GOVERNMENT PRINTING OFFICE: 1940

PUBLICATIONS of the PUBLIC ROADS ADMINISTRATION

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.

Report of the Chief of the Bureau of Public Roads, 1939. 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 6–8 and 10–19, 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, 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 GRADE CROSSING PROJECTS

AS OF OCTOBER 31, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			Estimated Total Cost	Federal Aid	NUMBER			
			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise			Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 4,100	$ 4,100			1	$ 720,404	$ 700,327	6		1	$ 47,539	$ 47,539	1	1	7	$ 916,112
Arizona	192,342	184,976	3			179,037	178,688	1			6,006	6,006			2	242,091
Arkansas	85,999	85,999	1		6	1,245,833	1,241,467	12	1	1	144,553	144,553	1		9	332,818
California	238,449	238,449	3		3	828,771	650,291	2	1		507,007	505,045	6		12	1,227,650
Colorado						283,222	283,222	1			3,401	3,401			1	921,104
Connecticut	270,224	264,463	1	1		517,556	512,317	6								449,334
Delaware	65,760	65,760			12	117,498	117,498	1		4	13,839	13,839	4		1	467,605
Florida	207,524	203,025	2		2	37,626	37,626	1			194,523	193,998		1	25	1,220,136
Georgia	100,753	100,658	2		12	895,795	895,795	11	5		531,974	531,974	2	4	6	1,735,588
Idaho	206,100	202,670	5		2	8,830	8,830			1	89,237	89,237			31	413,990
Illinois	600,672	547,061	4	1	23	2,294,881	2,084,758	9	1	49	215,158	184,666			77	1,975,749
Indiana	262,468	262,468	1	1	35	877,185	877,185	6	1	38	87,075	87,075			27	991,923
Iowa	292,444	239,250	3		42	312,391	275,233	3		39	64,788	61,696			19	1,205,976
Kansas	563,185	563,185	8		11	409,294	408,816	4	1	3	122,900	122,900	3	1	11	1,157,399
Kentucky	170,478	169,935	4		11	1,037,019	1,037,019	11			35,400	35,400	1		3	549,281
Louisiana	95,496	95,496	1			345,122	291,627	2			627,884	570,153	11			804,609
Maine	157,399	156,481	1	1	5	21,934	21,934		1	1	125,990	125,990	1			251,016
Maryland	180,997	180,993	1		2	476,609	444,816	2	2	5	15,600	15,600			3	767,315
Massachusetts	15,710	15,710				336,590	326,168	1			1,034	1,034			1	2,024,008
Michigan	941,190	907,876	7	1	18	1,418,695	1,418,695	3	4	5	104,950	104,950		1	18	743,016
Minnesota	766,380	758,524	8	1	6	1,254,907	1,254,907	8	4	8	213,272	213,272	1	2	6	1,009,406
Mississippi	23,760	23,760				628,634	628,634	9	1		275,000	275,000	3		3	503,012
Missouri	541,321	541,321	1	2	1	1,455,654	1,167,274	6	3		1,055,014	826,484	4	2		973,697
Montana	427,675	427,675	5		2	82,097	82,096	1			9,155	9,155			3	350,584
Nebraska	204,949	204,949		1	7	741,392	741,392	11	1	3	302,249	302,249	5		1	265,549
Nevada	11,144	11,144			7	125,527	125,527	2		6	21,199	21,199			12	115,071
New Hampshire	100,989	100,953	3			149,458	148,638	3		1						325,194
New Jersey						792,763	792,763	5		1	73,220	73,220		1	3	1,189,123
New Mexico	140,504	140,504	1		6	304,092	274,896	4								482,206
New York	428,630	427,120	3	1		3,786,319	3,718,553	9	19		244,245	240,245		1	8	2,831,215
North Carolina	164,092	164,029	1	1	13	989,429	989,189	13	5		95,530	95,530			27	818,777
North Dakota	448,315	448,150	5		15	404,220	404,220	4		6	5,700	5,700			2	528,663
Ohio	369,098	347,336	4		2	2,462,415	2,413,225	10	3	13	818,157	790,393	4		2	2,235,007
Oklahoma	253,288	252,261	2	1	24	591,587	590,240	10		1	205,628	202,212	1		43	1,880,962
Oregon	208,639	117,537	3			254,208	197,981	1			5,790	5,790			2	357,935
Pennsylvania	618,267	618,267	8	1		1,878,155	1,868,351	13	1		1,328,418	1,324,918	9	2		3,077,356
Rhode Island	3,831	3,750				192,501	192,501		1							94,451
South Carolina	325,148	325,148	4	2	7	184,294	183,891	1	1	12	162,832	162,832			31	916,503
South Dakota	72,600	72,600	1	1	2	282,902	282,042	7		2	462,535	446,585	10			739,692
Tennessee	204,265	204,265	1	2		173,264	173,264	1	1		34,462	34,462		1		1,715,788
Texas	1,145,408	1,140,600	10		3	1,181,428	1,171,063	10	1	6	77,700	77,700	1		2	1,998,980
Utah	12,419	12,208			3	37,963	37,963			10	108,747	108,640	2		40	246,680
Vermont	5,995	5,995			2	218,520	218,520		2	4	25,623	25,623			4	220,367
Virginia	81,101	80,765	1	2	3	691,669	690,339	6		2	140,842	140,842		2	10	593,601
Washington	242,856	242,856	3	1	5	123,070	121,570	1	1		198,172	198,168	1	2	7	390,610
West Virginia	5,400	5,400			2	229,982	229,982	2			66,670	64,580	2		1	1,079,957
Wisconsin	815,489	799,460	6	3	7	470,132	441,102	3	1	3	17,167	17,167			5	1,365,384
Wyoming						540,923	540,923	5			22,086	22,085	1			171,492
District of Columbia						59,061	59,061	1								150,009
Hawaii						194,036	194,028	2			9,494	9,494			2	292,509
Puerto Rico						584,007	579,336	11								414,857
TOTALS	12,272,853	11,965,132	117	24	302	33,428,901	32,325,783	241	62	225	8,917,765	8,538,601	74	21	467	45,731,357