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DETERMINING DEPTH TO ROCK BY MEASURING EARTH RESISTIVITY

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In This Issue

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SUBSURFACE EXPLORATION BY EARTH RESISTIVITY AND SEISMIC METHODS

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by E. R. SHEPARD, Research Engineer

DURING the past 2 years the Bureau of Public Roads has experimented with two geophysical methods of subsurface exploration, with the expectation that they will prove of value in foundation exploration, in the location of gravel deposits and other surfacing material, and even as an aid to classifying excavation in highway construction.

One of these methods of test—the electrical resistivity method—has been used for some years with varying degrees of success by several State highway organizations in connection with grading operations, fills through swamps, and for determining the location and extent of gravel deposits and quarry material.

The other method, known as the "seismic method", although used extensively for locating salt domes and other oil-bearing structures and in certain types of mining operations, has not heretofore been applied to shallow determinations. However, tests by the bureau over a period of several months on known formations around Washington indicate that, for determining the presence and location of consolidated rock, this method is more reliable and accurate and in other ways superior to the resistivity method.

These and other scientific methods of subsurface exploration are not new to the geophysicist. For many years the magnetometer has been used in the location of mineral deposits. The Eötvös torsion balance, a gravimetric instrument, was introduced into this country from Germany about 1922, and through its use many salt domes rich in oil and sulphur were discovered in the Gulf Coast region.

More recently the seismic method of exploration has come into use and is now the most popular and widely used of all geophysical methods for deep exploration work. Various electrical methods of exploration are also in use; of these the resistivity method is finding much favor where relatively shallow determinations are involved.

UNDERGROUND CONDITIONS INDICATED BY ELECTRICAL RESISTIVITY

In using the resistivity method of exploration the most common procedure is to introduce an electric current of known strength into the earth through suitably placed electrodes and by means of intermediate electrodes to measure the average resistivity of a volume of earth comparable in dimensions to the electrode spacing. By progressively increasing the electrode spacing and repeating the measurements a curve is established which shows the relation of resistivity to depth.

Calculated values of resistivity are plotted as ordinates and corresponding values of electrode spacing as abscissas. An upward trend of the curve indicates increasing resistivity with depth and suggests the presence of rock, gravel, or some other high-resistance material, while a flat or descending curve is indicative of soil or clay. An abrupt change in curvature indicates a change in material at a depth approximately equal to the electrode spacing at which the change occurs.

Studies of this kind have been reported by the Bureau of Mines (*4, 5, 6, 9*),[1] by Schappler and Farnham (*8*) of the Missouri State Highway Commission, by Kurtenacher (*2, 3*) of the Wisconsin Highway Commission, by Wilcox (*12*) of the Minnesota Department of Highways, and by numerous other investigators. Schappler and Farnham were successful in preclassifying excavation materials on highway projects but had difficulty in interpreting bridge sounding data due to the fact that coarse sand and gravel overlying the bedrock possessed a resistivity not markedly different from that of the solid rock. Kurtenacher reported success in the determination of the thickness of stripping in quarries, the location of buried gravel deposits, and the determination of depths to solid bottom in marshes and swamps. Wilcox has confined his work largely to locating shallow deposits of sand and gravel for road surfacing.

The following quotation from the report of Schappler and Farnham shows that in 1931, without the aid of resistivity measurements, an error of nearly 13 percent was made in estimating the amount of solid-rock excavation on a number of highway jobs, while in 1932, on a like number of similar jobs where estimates were based on resistivity tests, the error was about 1 percent. This comparison suggests the possibility of greatly improving the accuracy of estimates of grading costs on highway projects through the use of this or other methods of preliminary exploration.

> Up to date final estimates have been filed on 25 projects completed in 1932, on which geologists had made reports and preclassified the excavation. The projects were matched as nearly as possible with projects completed in 1931. On the basis of this comparison it was found that the present scheme of preclassifying predicted that 8.32 percent of all the excavation quantities would be solid rock, whereas final estimates consider 9.36 percent of the excavation as solid rock—an overrun of 1.04 percent. In 1931 preliminary classification predicted 21.79 percent solid rock whereas final classification gave 8.87 percent or an underrun of 12.92 percent. Limiting this comparison to 15 projects typical of the more difficult area—the Ozark region—in 1932 final classification overran the predictions 3.13 percent, while in 1931 there occurred an underrun of 24.44 percent. Although this analysis is far from complete, it does express the general results of this method of preclassifying excavation materials. Predictions are more nearly accurate than formerly and instead of the tendency to greatly overclassify the solid rock the present trend is toward slightly underclassifying.

PRINCIPLES INVOLVED IN RESISTIVITY MEASUREMENTS DISCUSSED

The principle involved in making earth-resistivity measurements is illustrated in figure 1. An electric current, I, is caused to flow through the earth between two electrodes, C_1 and C_2. Measurement is then made of the potential drop, E, between two intermediate electrodes, P_1 and P_2, placed in line with C_1 and C_2 and dividing the distance C_1C_2 into 3 equal parts, A, termed the electrode spacing.

In 1915 Wenner (*11*) showed that with this 4-electrode arrangement the specific resistivity of a homogeneous medium is given by the equation,

[1] Italic numbers in parentheses refer to literature cited on p. 74.

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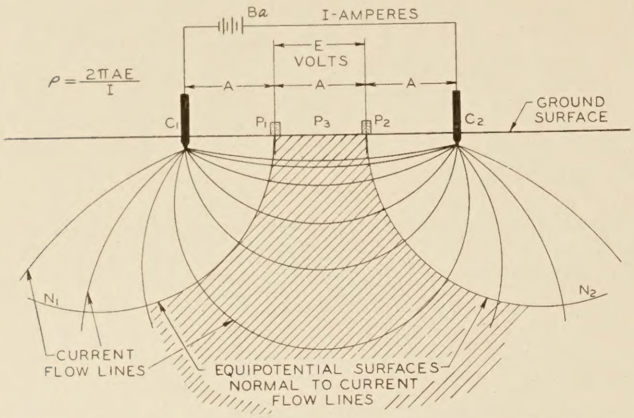


FIGURE 1.—DIAGRAM FOR USE IN DISCUSSING THEORY OF EARTH RESISTIVITY MEASUREMENTS.

$$\rho = \frac{2\pi AE}{I} \tag{1}$$

where A is expressed in centimeters. The specific resistivity, ρ, is expressed in ohm-centimeters and denotes the resistance in ohms between parallel faces of a centimeter cube of the material. Where A is measured in feet we may write,

$$\rho = 191A\frac{E}{I} \tag{2}$$

If the medium is not homogeneous the indicated resistivity, ρ, represents an average specific resistivity of the material bounded by the equipotential surfaces P_1N_1 and P_2N_2 but its value is determined largely by the properties of the material near the surface and only slightly by the material at a relatively great depth. The experience of numerous investigators is rather consistent in showing that for practical depth determinations the materials within a depth equal to the electrode spacing, A, largely determine the value of ρ, and that materials at a depth greater than A have a negligible influence on the value of ρ.

Let us assume in figure 2 that a homogeneous soil of resistivity ρ_1 exists to a depth H and that below the horizon H a material of greater resistivity ρ_2 exists. If, under this condition, earth resistivity measurements are made with different values of electrode spacing, A, as indicated in figure 1, and a curve is plotted showing the relation of ρ to A, as in figure 2, we find that for values of A less than H the curve ab is approximately flat, but when A begins to exceed H the influence of the deeper material begins to affect the value ρ and the curve assumes an upward trend as at b. Rather abrupt changes of this kind are often obtained in practice and afford a means of roughly determining the depth to a change in material. This is a simple empirical rule, but one for which there is no theoretical basis.

Tagg (*10*) and others have shown that from theoretical considerations the curve in figure 2 should assume some such form as a′bcd with no sharp breaks or inflections. In practice, however, and especially on shallow work, rather sharp inflections are frequently obtained where materials of different resistivities are concerned, and these inflections afford a simple and satisfactory means of ascertaining the approximate depth where the change in material occurs.

Perhaps a more common occurrence is a U-shaped curve in which the electrode spacing at the low point

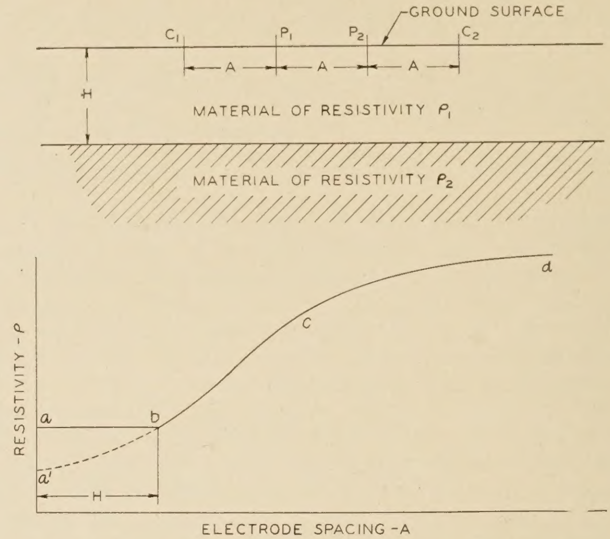


FIGURE 2.—TYPICAL RESISTIVITY CURVE.

is taken as the depth to a change in material. The descending branch of the curve is characteristic of many soils in which a decreasing resistivity occurs with increase in depth. Under such conditions an underlying strata of rock or gravel is indicated quite accurately by the low point of the curve.

VARIOUS TYPES OF INSTRUMENTS USED FOR RESISTIVITY MEASUREMENTS

Three types of instruments are being used for earth resistivity measurements, and each has its advantages and disadvantages. As the men who are often called upon to do this class of work are more likely to have had technical training in geology or civil engineering than in electrical science, it will be appropriate to discuss the several methods and instruments currently employed, in order that the most suitable arrangement of apparatus may be selected to meet any particular set of requirements. Before discussing the instruments themselves, it will be well to consider certain inherent difficulties that are encountered in earth-resistivity measurements.

The measurements indicated in figure 1 are not as simple as they are here made to appear. Several sources of stray currents and potentials are likely to exist and must either be eliminated or compensated for if an accurate determination of E, the potential drop in the earth between P_1 and P_2, resulting from the current I, is to be obtained. These sources are, (1) self potentials originating in local mineral deposits; (2) natural earth currents of large scope but not often of troublesome magnitude; (3) local stray currents originating from street-railway systems, grounded power circuits, or mine railways. These are usually variable in character and are especially troublesome near large city-railway systems or interurban electric lines. Other sources are, (4) galvanic and polarization potentials between electrodes P_1 and P_2; (5) galvanic potentials originating from cinders, coke, or filled ground containing bits of metal or other foreign materials.

In addition to overcoming these stray-current effects, it is necessary to avoid taking any current from the electrodes P_1 and P_2 while making a measurement of E, as a flow of current through these electrodes will distort or upset the true potential difference between them resulting from the flow of the current I. This latter condition is usually met by employing a potentiometer, which draws no current from the potential source being measured, or a voltmeter or galvanometer of extremely high resistance that draws a negligible current from the electrodes. To overcome the stray-current effects it is customary to use alternating current or its equivalent—a periodically reversed current—as stray-current effects are essentially unidirectional and are not recorded on the instruments that measure the alternating or periodic current.

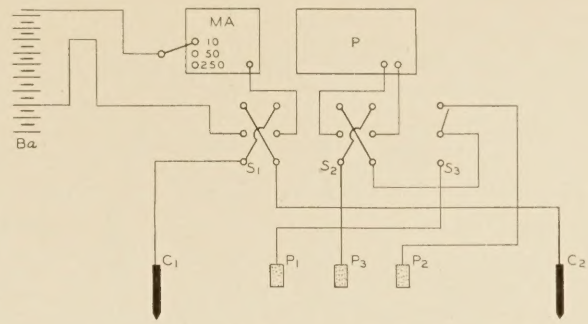
In his original paper, Wenner proposed the use of alternating current supplied from a transformer. A vibration galvanometer was so placed in the circuit as to detect a balance between the voltage at the electrodes P_1 and P_2 and that on a measured length of slide wire supplied from the secondary side of the transformer. A balance was indicated when no current flowed through the galvanometer. Such apparatus is obviously not suited to rapid field measurements.

The first practical application of the four-electrode method of measuring earth resistivity was made by McCollum (*7*) of the Bureau of Standards in a study of stray-current electrolysis on underground pipes and cable systems. The McCollum earth-current meter embodies a dry battery, a milliameter, a double commutator, and a voltmeter having a resistance of 1,000,000 ohms per volt. Current, after passing from the battery through the milliameter, is commutated at a frequency of about 30 cycles per second and then conducted to the two current electrodes. This periodic current establishes a potential difference of the same frequency between two potential electrodes. Leads from the potential electrodes are carried to a second commutator mounted on the same shaft with the current commutator and in phase with it. The effect of this second commutator is to rectify the periodic potential, after which it is measured on the direct-current, high-resistance voltmeter. It will readily be seen that any direct stray current which may exist in the earth should not affect the direct-current voltmeter because of having first passed through the potential commutator.

A set of four electrodes mounted on a frame as a unit, with a 3-inch interval, is commonly used with the earth-current meter in the study of stray-current electrolysis. Although this instrument is extensively used on electrolysis work, it apparently has not found application in geophysical exploration. There is no reason, however, why it should not be used for this purpose and it might prove particularly suited to shallow determinations.

Gish (*1*) of the Department of Terrestrial Magnetism and Atmospheric Electricity of the Carnegie Institute modified the McCollum earth-current meter and measured the resistivity of large volumes of earth. His instrument embodied a larger and more accurate commutator than that employed by McCollum and he substituted a potentiometer for the high-resistance voltmeter. He also introduced a condenser into the potential circuit to block the passage of galvanic and stray direct currents from the ground to the potentiometer, and reduced leakage between the current and the potential circuits by the addition of a guard ring. This type of apparatus has been used quite extensively for geophysical explorations during recent years.

Another instrument, known commercially as the "megger" (*4*), was designed primarily to measure the resistance of driven and buried grounds for power stations and electric circuits, but is also used successfully under certain favorable conditions for subsurface exploration. It embodies a hand-driven, direct-current generator, a double commutator on the same shaft with the generator, and a single indicating instrument known as an "ohmmeter." By a special arrangement of the coils and magnetic circuit this meter is made to register the ratio $\frac{E}{I}$ and thus indicates ohms directly. The fact that this instrument must, of necessity, draw current from the potential electrodes is distinctly a disadvantage. The error is not serious in determinations involving moderate depths if the contact resistance of the potential electrodes is kept reasonably low. Sometimes it is necessary to use water and rather long potential stakes. If accurate values of resistivity are desired, it is necessary to measure the resistance of each potential stake to ground and to compute certain correction factors based on these measured resistances.



Ba - 220 VOLT "B" BATTERY. MA - MILLIAMMETER.
C_1 & C_2 - CURRENT STAKES. P - POTENTIOMETER.
P_1, P_2 & P_3 - NON-POLARIZING POTENTIAL ELECTRODES.
S_1 - REVERSING SWITCH TO CHANGE DIRECTION OF CURRENT THROUGH GROUND.
S_2 - REVERSING SWITCH TO POTENTIOMETER TERMINALS.
S_3 - SWITCH TO CONNECT P_1 & P_3 OR P_2 & P_3 TO POTENTIOMETER

FIGURE 3.—CIRCUIT DIAGRAM FOR EARTH RESISTIVITY MEASUREMENTS.

Eve, Keys, and Lee (*4*) of the Bureau of Mines have shown that comparative values of resistivity as obtained with the megger are often subject to the same interpretations as are similar data obtained by more precise methods. An improved megger, designed especially for geophysical work, and embodying a potentiometer, is said to be available now.

METHOD DEVISED FOR MAKING RESISTIVITY DETERMINATIONS RAPIDLY

Among the several methods of test used by the Bureau of Mines (*9*) is that embodying a simple direct-current circuit with a reversing switch instead of a commutator. Nonpolarizable potential electrodes are also substituted for the conventional iron stakes. Lee (*5*) also introduced a center potential electrode with which it is possible to determine underground slopes by making independent measurements on either side of the center. This type of apparatus is the one adopted and used by the Bureau of Public Roads.

Its essential features are shown in figures 3 and 4. Special potential electrodes are used to minimize polarization and galvanic potentials. They consist of a copper electrode submerged in a concentrated solution of copper sulphate in an unglazed porous cup. Cups 10 centimeters high and 5.2 centimeters in diameter

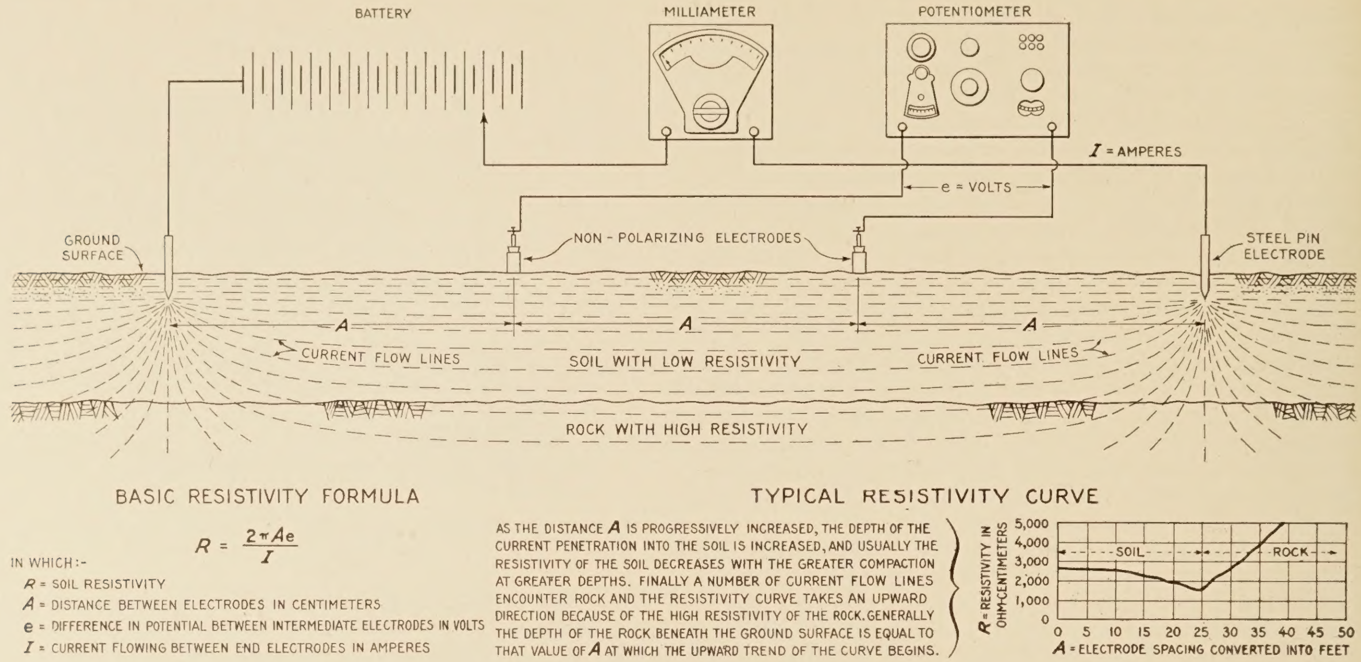


FIGURE 4.—ARRANGEMENT OF APPARATUS FOR MEASURING ELECTRICAL RESISTIVITY.

are used. When not in use they are kept in an earthen jar containing a solution of copper sulphate. They should not be brought in contact with metals. Iron stakes 1¼ inches in diameter and about 2 feet long are used for current electrodes.

A milliammeter having ranges of 10, 50, and 250 milliamperes and a potentiometer are mounted on a 12- by 21-inch oak board, together with the switching arrangements shown in figure 4. The milliammeter is elevated to the same level as the face of the potentiometer and the switches are installed on the vertical front of its support. Leads of no. 18 lamp cord are used. These are wound on 4 brass spools which are mounted on a 9- by 12-inch board. This unit is provided with a flat bayonet attachment by which it is mounted on the back of the instrument unit when in operation. Another unit containing batteries, and two folding camp stools completes the equipment. The battery box provides for 9 "B" batteries of 22½ volts each, with additional space for tapelines, connecting leads, and porous cups. Two leads connect the battery to the instrument, and a dial switch on the top of the battery box enables any number of the units to be connected in circuit. Plugs and jacks are used to connect the lead terminals and the battery to the instrument, and small battery clips are used to connect the leads to the ground electrodes.

To eliminate the effect of any stray ground current of a constant and unvarying character, readings are taken with the test current flowing through the ground, first in one direction and then in the other. The reversing switch, S_1, is used to reverse current direction. Potential drop readings are taken between P_3 and P_1 and between P_3 and P_2 for both directions of current flow. Four values of current and four values of potential drop are thus obtained for each electrode setting, and from these data four values of R are computed with the formula $R=\frac{E}{I}$. Resistivities are computed by substituting in equation 2 after adding the two values of R obtained on either side of the center. If the two values of R are averaged, then a constant of 382 instead of 191 must be used in equation 2. By repeating these measurements for a series of electrode spacings, it is possible to construct two resistivity curves as shown in B, C, D, and E, figure 5, which apply along the line of test on either side of the center electrode.

A fairly rapid technic has been developed which enables 2 engineers and 2 helpers to make from 10 to 20 shallow tests per day. By shallow tests is meant those involving such depths as are encountered in highway grading through rough country and requiring from 6 to 20 measurements at each test location. An electrode spacing of 3 feet, or multiples thereof, has been adopted as standard and both current and potential stake locations are marked on the plain side of two 100-foot linen tape lines to conform to a 3-foot interval. Potential electrode locations are marked by consecutive numbers in red while every third position is marked consecutively in black to indicate current stake positions. The end links of the two tapelines are brought together at the center point of the test and a surveyor's iron pin stuck through them and into the ground. The tapelines are then run out to their full length in either direction and pinned to the ground in a taut position. With 1 man to read the instruments, 1 to record the data and compute the resistivities with a slide rule, and 2 helpers to move the electrodes progressively from point to point, it is possible to run a 60-foot depth test in from 30 to 40 minutes.

EQUIPMENT LOW IN COST AND GIVES ACCURATE RESULTS

The curves are plotted before moving and any irregularities are checked on both paper and ground before leaving the set-up. Sometimes it is desirable to obtain additional points on the curves in order to definitely establish the points of inflection. By this procedure it is usually possible to obtain fairly smooth and consistent curves. No sharp inflections have been found except at shallow depths. The jagged and pointed curves reported by some investigators for depths of

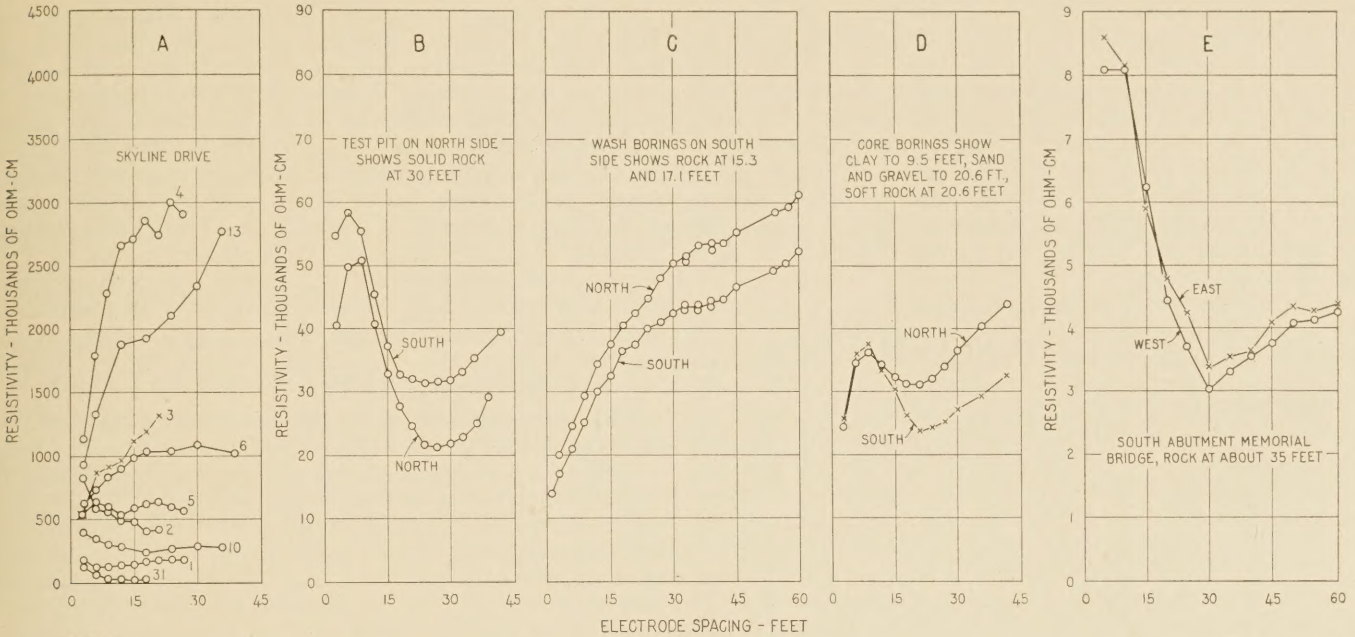


Figure 5.—Results of Earth Resistivity Measurements.

several hundred feet cannot be reconciled with either theory or careful practice.

Some trouble from stray current from electric railways has been encountered in and near Washington when attempting depth measurements in excess of about 50 feet. This difficulty can usually be met by using sufficiently large test currents to mask the effects of the variations in the stray currents and by taking the average of several readings for each electrode interval. It seems probable, however, that active stray currents will preclude the use of this method of measurement for depths in excess of 100 to 200 feet. To compensate for this disadvantage there are a number of advantages that make this so-called "porous-cup" method of test preferable to all others. These include low cost of equipment and high accuracy under a wide range of depths and resistivities.

When working in soils of unusually high resistivity, especially during dry periods, it is sometimes difficult to get enough current through the potential electrodes to operate the megger and other commutator devices. Even though a potentiometer is used in the potential circuit, the small amount of current required to charge the leads is sometimes sufficient to upset the normal potential relations. The only effect of such a condition when using the porous-cup method is a reduced sensitivity of the potentiometer galvanometer caused by the high resistance of the circuit. However, as no current is actually drawn from the potential electrodes, a satisfactory balance is always obtained. The porous cups are placed directly on the ground surface. Leaves, grass, and trash are usually removed. Unless the soil is dust-dry, no difficulty is encountered in obtaining satisfactory readings. With other types of apparatus it is often necessary to water the electrodes or drive them to a considerable depth. One case is reported where potential stakes 12 feet in length were used in connection with megger tests.

The paper and slide-rule work involved in the porous-cup method is somewhat greater than with other methods of test because of the necessity of making four sets of observations for each electrode interval. With the Gish-Rooney apparatus only two sets of readings are necessary, while with the megger no division operations are required as the instruments indicate ohms directly. It is necessary, however, to multiply the megger readings by a constant and by the electrode spacing to obtain actual resistivity values.

As to weight and portability, the megger and the earth-current meter are about on a par, and both are considerably lighter than either the Gish-Rooney or the porous-cup apparatus. None of the instruments require very accurate leveling. The Gish-Rooney apparatus is scientifically more accurate than any of the others and will perhaps yield satisfactory data for a greater variety of conditions than the others. For the relatively shallow depths encountered in highway construction, as well as for deeper determinations where stray-current disturbances are absent, the porous-cup apparatus appears to be entirely satisfactory and is favored because of its low cost and its simplicity of construction and operation.

FIELD TESTS MADE WITH RESISTIVITY APPARATUS

Resistivity measurements carried out by the Bureau of Public Roads have been confined largely to experimental studies of known formations for the purpose of developing suitable apparatus and methods of test and to determine the conditions under which this method of exploration may be of value in planning highway and bridge construction. Army engineers have made many borings in and about Washington in connection with the planning of bridges and other structures and these data afforded an excellent opportunity to check resistivity tests against the logs of these borings.

A period of several weeks was spent along the projected route of the Skyline Drive in the Shenandoah National Park, on both graded and ungraded sections. Preliminary measurements were made opposite cuts along graded sections prior to working along sections where grading was soon to begin. Part of the route on which measurements were made was examined after the grading had been completed and comparisons made between the field notes and the exposed cuts. Figure 5 shows a few of the many resistivity curves obtained. The curves in group A, figure 5, were all made along graded sections of the Skyline Drive, while curves B, C, D, and E were obtained near Washington. In group A only one of the two curves obtained at each location is shown.

Perhaps the most significant features brought out by these studies are the wide range in resistivities of both soil and rock encountered within a comparatively limited area, and the lack of uniformity and regularity in the upper layers of the earth's crust. Soil resistivities often vary enormously from hill to hill, and adjacent mountains may exhibit distinctly different characteristics with respect to soil and rock. Igneous intrusion, sedimentation, erosion, faulting, weathering, folding, and other geologic forces have contributed to make the earth's surface so erratic and irregular in its composition that no systematic continuity of materials is to be found, especially in rough or mountainous areas. Because of these conditions, the interpretation of resistivity measurements is often indefinite or uncertain and frequent correlations with known conditions should be made wherever possible.

Figure 5 shows the enormous range in resistivities encountered within the space of a few miles along the Skyline Drive. In spite of this wide range in resistivity the shape of the curve can usually be depended upon to indicate the character of the underlying material. Flat or drooping curves such as 1, 2, 5, 10, and 31, usually indicate earth or loose rock, while ascending curves such as 6, 3, 13, and 4, indicate the presence of rock. Near Front Royal, Va., some 20 miles north of Panorama, resistivity values for both soil and rock are much lower than those shown in figure 5. Earth resistivity as low as 6,000 ohm-centimeters was found at an elevation of 1,000 feet, as against values of 100,000 to 400,000 ohm-centimeters near Panorama at an elevation of more than 2,000 feet.

Rock resistivity was also found to vary over wide limits, and in one location was so low as to fail to give indication of its presence. Although not all of the 10 miles of right-of-way explored has been examined subsequent to grading, enough has been checked to prove that such tests should provide highly valuable information to bidders and contractors.

Precise classification cannot be expected but it should be possible to identify 2 and possibly 3 kinds of material, such as earth, broken or loose rock, and consolidated rock. After all, the contractor is primarily interested in knowing if he can handle the material with his shovel or whether he will need to resort to blasting. The resistivity test can give him the answer in the great majority of cases.

Curves B, C, D, and E, in figure 5, were made in an area near Washington where rock depths had been determined by a large number of test pits and borings. Curves B and D are typical of most of the area where good checks were obtained by taking the electrode spacing at the lowest point on the curve as the depth to rock. However, in a few instances curves like those shown in C were obtained. In such locations the relative resistivities of the different strata are such as to obscure the location of the rock.

Curve E was obtained at the south abutment of the Arlington Memorial Bridge where the bed rock is known to be about 35 feet from the surface. Although there is undoubtedly a great difference between the resistivity of the overlying muck and that of the rock, the sharp inflection in these curves is somewhat surprising and in strong contrast with other measurements along the Potomac River where positive identification of the rock at depths of from 40 to 70 feet has not been possible. As the changes in curvature occur in the curves representing conditions east and west of the reference point, they cannot logically be attributed to local surface conditions near the current stakes.

RESISTIVITY ABOUT A SINGLE ELECTRODE DISCUSSED

The single-electrode method of measuring earth resistivity, that has found favor with some investigators, is illustrated in figure 6. If a currrent, I, is made to flow through the earth between electrodes C_1 and C_2, we may assume that the flow of current from C_1 into a homogeneous soil will be radial if C_2 is at a comparatively great distance from C_1. With a radial flow of current from C_1 we can express the resistivity of the medium by the equation

$$\rho=191\frac{E}{I}\,\frac{r_1r_2}{r_2-r_1}\qquad(3)$$

where E is the potential drop between the two equipotential, hemispherical shells P_1P_3 and P_2P_4, and r_1 and r_2 are expressed in feet. The material for which ρ is obtained is that enveloped between the two concentric shells and designated by shading in figure 6. By progressively increasing r_1 and r_2 and measuring the potential drop, P_1P_2 or P_3P_4, a curve is obtained showing the relation of ρ to r_2. This curve will be similar to that obtained by the 4-electrode method and is supposed to indicate changes in material in the same manner, since the material included in the test has a depth equal to r_2.

As r_1 and r_2 are increased, the equipotential shells deviate more and more from a true hemisphere because the current stake C_2 is not at an infinite distance from C_1. The error introduced by the dissymmetry of the electric field about C_1 is shown by the curves of figure 7 and is seen to be greater in the direction toward C_2 than away from it. For this reason it is preferable to make potential difference measurements at P_3P_4 rather than at P_1P_2.

One advantage that has been claimed for this method of test is that the current stakes remain fixed during any depth test and therefore the results are not subject to the influence of local surface variations near the current stakes, as may occur with the 4-electrode method. In the work described here, this method was not investigated to any great extent but in the few comparative tests which have been made between the two methods, the 4-electrode method was found to give the smoother and more consistent curves.

SEISMIC METHOD BASED ON DIFFERENCES IN SPEED OF SOUND WAVES THROUGH SOIL AND ROCK

In using the seismic method of exploration advantage is taken of the wide difference in the acoustic properties of plastic and granular matter on the one hand and rigid or consolidated matter on the other. Nonrigid matter such as sand, clay, or gravel transmits wave disturbances, commonly called sound waves, at velocities of 1,000 to 6,000 feet per second, while rigid materials like

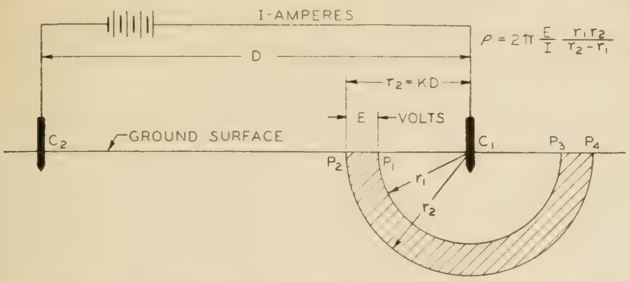


FIGURE 6.—RESISTIVITY ABOUT A SINGLE ELECTRODE.

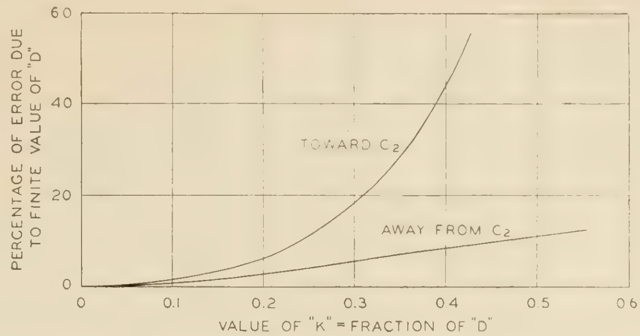


FIGURE 7.—ERROR IN SINGLE-ELECTRODE METHOD.

rock or crystalline matter transmit such disturbances at 16,000 to 20,000 feet per second. Here, then, we have a means of measuring directly that property of subsurface materials with which the engineer is concerned, namely, rigidity, while the resistivity method is used in attempts to measure this property indirectly or through its somewhat questionable relation to electrical resistivity. The seismic method is, therefore, more definite in the identification of solid rock than is the resistivity method but cannot readily be used to distinguish between clay and coarse sand or gravel, as can often be done with the resistivity method.

In view of the success with which the seismic method of exploration has been applied to oil prospecting, and in view of the fact that it is distinctly the most favored of all geophysical methods, it is somewhat surprising that it has not heretofore been adapted to relatively shallow determinations. Perhaps the reason for this is to be found in the array of apparatus and equipment ordinarily required and the cost of such operations as commonly carried out. The Oil and Gas Journal, referring to recently developed seismic reflection equipment for geophysical prospecting, says: "It consists mainly of two separate units, the recording truck and the firing car. The recording truck contains the seismometers or pick-ups (ordinarily 6), the amplifiers, and batteries, wire reels, the camera, as well as field telephone, and various other accessories. The firing car contains explosives, firing box, double reel, and telephone for cross communication with the recording truck. A drilling truck and water car are ordinarily added."

Anyone contemplating this array of cars and equipment might well question the practicability of the method as a substitute for the soil auger or other relatively simple methods of exploring shallow depths. Such equipment may be justified where the discovery of a new oil field may mean large profits to the operator but can it be applied efficiently in making less-important discoveries?

SEISMIC APPARATUS GREATLY SIMPLIFIED FOR USE IN SHALLOW WORK

It was believed that a large part of the equipment required for deep prospecting could be eliminated or greatly simplified in an apparatus designed primarily for relatively shallow work, and that a so-called "vest-pocket" model of the more extensive apparatus could be constructed to meet these requirements. The most important difference between deep and shallow exploration is the relatively short shooting distances involved in the latter and this has made the simplification of apparatus possible. Telephonic communication between shot point and recorder is not needed and most of the cumbersome wire and reels are eliminated. Only small charges of explosives are required and these can be placed in a 1¼-inch soil-auger hole, thus eliminating the heavy drilling equipment required in deep work. The short shooting distances also permit the use of less sensitive instruments and amplifying equipment is not needed.

With these modifications in mind apparatus was assembled, consisting of a 3-element oscillograph with camera for photographic recording, 3 microphonic detectors or pick-ups and two 6½-inch spools of wire. Accessories consist of 2 camp stools, one 4-foot soil auger, 4 no. 6 dry cells or a small storage battery, 1 developing tank with developing and fixing solutions, and 1 changing bag. The whole outfit, together with a crew of 3 men, can be carried in a small car and can be set up for operation in about 10 minutes.

The laborious calculations in the application of involved formulas often necessary in deeper determinations can be dispensed with where shallow structures are concerned, and in their place a simple equation substituted, requiring only a mental calculation or, at most, a slide-rule operation for its solution.

The essential units of the apparatus used are shown in figures 8 and 9. The detectors seen at the right in figure 8 are of the microphonic type and consist of four microphone buttons connected in parallel and mounted with axes vertical. The mica diaphragms have been replaced with dental rubber diaphragms that carry polished carbon disks. These lower elements of the buttons are carried on a ring that is integral with a floating inertia weight in which gravity is balanced by a helical spring about 3 inches long mounted in the vertical neck of the detector. Lateral alinement is maintained by a thin steel spider diaphragm and stops limit the vertical movement of the inertia weight to less than one-sixteenth inch. The upper element of the button consists of a conical carbon chamber with polished surfaces and containing carbon granules.

The resistance of this assembly changes enormously with the slightest disturbance, thus making it a detector of exceptionally high sensitivity. While it is subject to some of the inherent defects of the carbon microphone, it is perhaps the only type of detector that can be used in the field successfully without amplifiers. This feature makes it particularly suited to shallow exploration work where simplicity and portability are of first importance.

When in operation each detector carries a current of from 5 to 10 milliampers supplied from dry cells or a small storage battery. This current passes through the primary coil of a transformer; the secondary coil is in series with a galvanometer of the oscillograph type.

The galvanometer, therefore, responds only to a change of current in the detector.

The galvanometers are of the coil type having a direct-current sensitivity of about 4 milliamperes per inch of deflection at 10 inches and an undamped frequency of 1,200 cycles per second. The elements, carrying small reflecting mirrors, are damped in oil. An optical system directs light from a 2.5 ampere, 4-volt, straight-filament lamp to the galvanometer mirror, from where it is reflected and brought to a point focus in the plane of a moving photographic film.

Time lines on the film are obtained from "peep slits" carried on the tines of an electrically driven tuning fork customary to cut the film after every third or fourth shot.

Standard, supersensitive, motion-picture film is used as it was found that less-sensitive film did not give sufficiently dense traces. Records are developed in a dark room when convenient, or in a Leitz developing tank in the field. A changing bag is needed in transferring the exposed film from the camera to the developing tank.

This equipment, with the exception of the detectors, was built in the shop of the bureau, after purchasing such items as galvanometers, tuning fork, lenses, and minor electrical supplies.

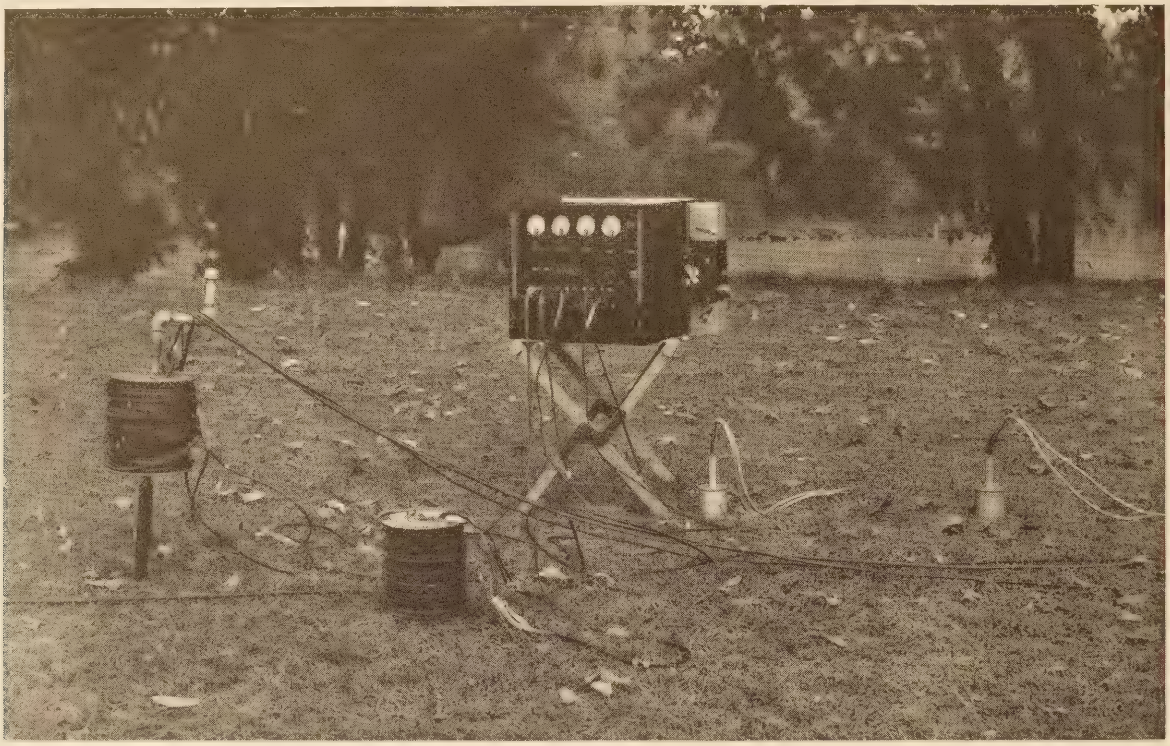


FIGURE 8.—ELECTRICAL SEISMOGRAPH SET UP FOR FIELD USE.

that vibrates at a normal frequency of 100 cycles per second. The slits are one-half inch long and 0.01 inch wide and coincide in the neutral position of the fork and therefore give two lines for each complete cycle of the fork. The timing requires an independent lamp and optical system with the exception of the cylindrical lens (mounted immediately in front of the film) which is common to both light systems.

The camera used for moving the film is an adaptation of a Sept camera, an obsolete, amateur motion-picture camera of French manufacture, which carries a 35-millimeter film. A direct drive was substituted for the intermittent motion and other necessary changes were made. A spring motor drives the film at approximately 2 feet per second. The film attains its maximum speed almost instantly upon starting the motor and permits a record to be obtained with a film consumption of about 18 inches. A numbering lamp and two dials of perforated numbers were installed in the camera and make it possible to number films photographically from 0 to 99. This feature enables definite identification of records after development. A film cutter operated by a trigger is provided to cut the film whenever desired. As the developing tank accommodates 6 feet of film it is

DETERMINATIONS BASED ON ELEMENTARY PRINCIPLES

Two methods of seismic exploration that are in common use are known respectively as reflection shooting and refraction shooting. These terms have the same significance in geophysics that they do in optics, as the mathematical theory of transmission of sound-waves through solids and liquids is based largely on the well-known laws of optics. In reflection shooting the interpretations are based on waves that are reflected directly from different strata under investigation, while in refraction shooting it is the refracted waves that are studied. As reflection shooting is not well adapted to shallow explorations, no further space will be given to description of that technique.

The principles involved in refraction shooting are illustrated in figures 9 and 10. A blasting cap or small charge of dynamite is exploded at or under the surface of the ground at some point, S, which becomes the center of a wave disturbance that moves outward on a spherical or near-spherical front in all directions. Detectors D_1, D_2, and D_3, placed on a line passing through S, pick up this disturbance successively and carry the impulses to three galvanometers that record them as light traces on a moving photographic film.

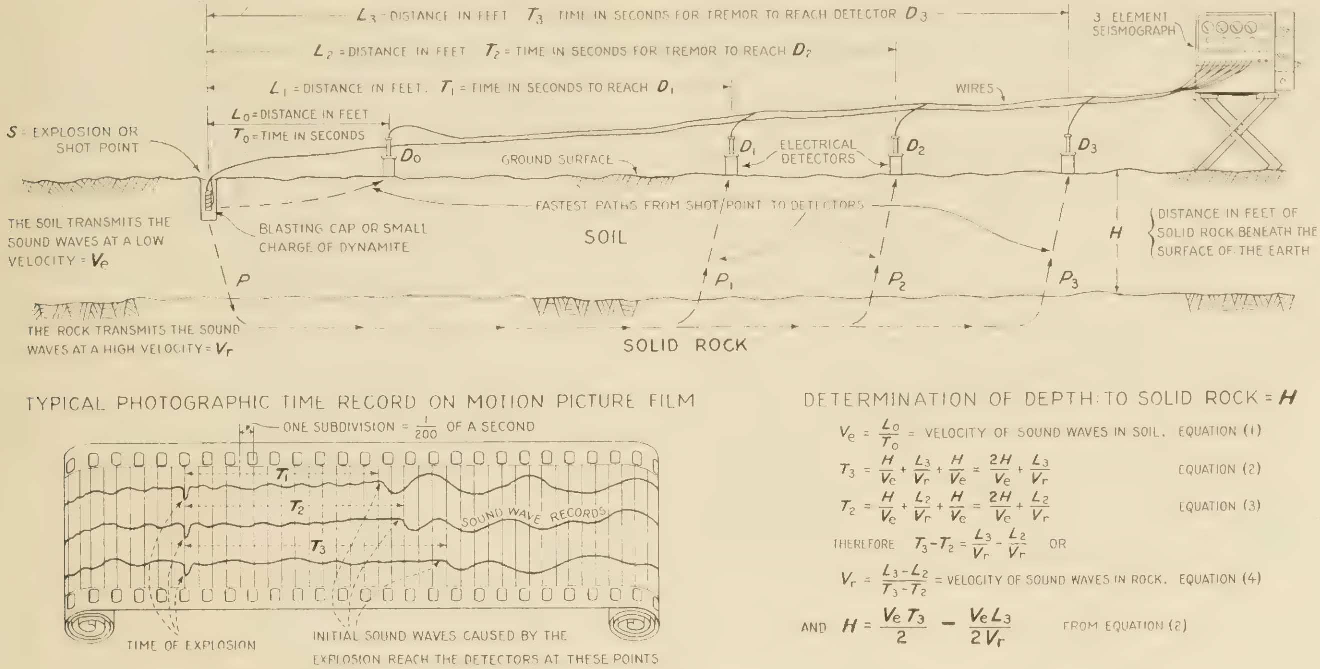


FIGURE 9.—SKETCH SHOWING FUNDAMENTAL PRINCIPLES OF SEISMOGRAPHIC METHOD.

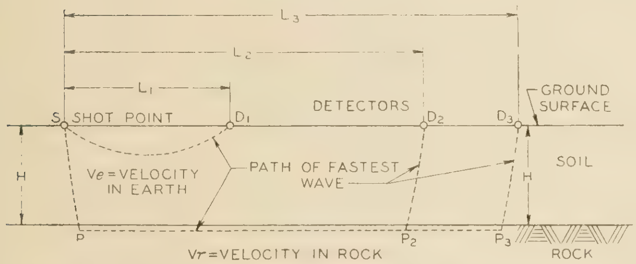


FIGURE 10.—WAVE PROPAGATION IN SEISMIC EXPLORATION.

A small wire is wound around the blasting cap and arranged so that when it is broken by the explosion an initial kick or impulse is given to the three galvanometers and the time of the explosion is thereby indicated on all three traces. As the wave front moves outward from S, its time of arrival at each of the three detectors is indicated on the moving film by disturbances in the traces as shown in figures 12, 13, and 14. By counting the number of time units between the initial kick and the arrival of the wave at each detector, it is possible to calculate the average velocity of wave propogation from shot point to each detector. From data of this kind it is usually possible to determine with a fair degree of accuracy the depth to the first strata of rigid or consolidated rock and to obtain other information of value regarding the character of the subsurface material.

Referring to figure 10, the path of the first wave to reach any detector will depend upon the ratio of the shooting distance, L, to the depth to rock, H, and also upon the relative velocities of wave propagation in the two media. If the shooting distance is relatively short, such as L_1, the path of the first disturbance to reach D_1 will be directly through the soil as indicated. The velocity of the wave through the earth can then be calculated from the equation,

$$V_e = \frac{L_1}{T_1} \tag{4}$$

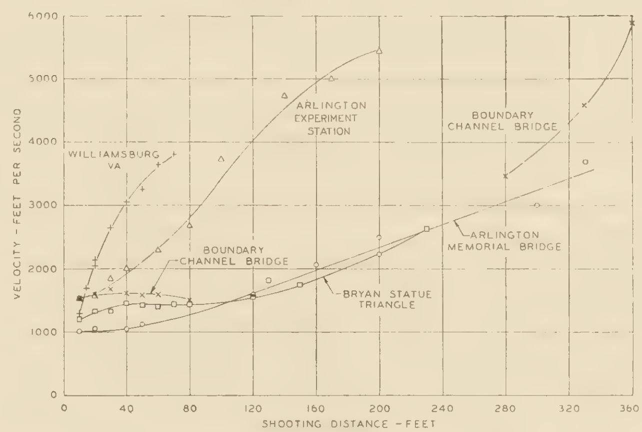


FIGURE 11.—RELATION BETWEEN VELOCITY OF SOUND WAVES THROUGH EARTH AS OBTAINED WITH THE ELECTRICAL SEISMOGRAPH.

As the shooting distance is increased, a point such as D_2 will be reached where the wave first to arrive will no longer be that going directly through the top soil but that taking the path of the refracted wave SPP_2D_2. Subsequent disturbances will reach detector D_2 by various paths but as only the first arrival can be definitely identified on the film record it is necessary to base interpretations solely on so-called "first events". Likewise the first wave to reach D_3 will be by the path SPP_3D_3. By measuring the time difference $T_3 - T_2$ and the distance $L_3 - L_2$ we are able to calculate the velocity of wave propagration through the rock from the equation,

$$V_r = \frac{L_3 - L_2}{T_3 - T_2} \tag{5}$$

This relation is obvious from the fact that the time difference $T_3 - T_2$ is taken up by the travel of the wave through the rock from P_2 to P_3, since that part of the path SPP_2 is common to both circuits.

We are now able to write the equation by which H, the depth to rock, can be calculated from known quantities. This is based on the fact that T_3, the total time of travel of the wave from S to D_3, is the sum of the combined times of wave travel over the path SPP_3D_3. Although refraction of the wave at the point P is supposed to take place at the angle of total internal refraction, we may assume with negligible error under practical conditions that this angle is 90° and that the distance PP_3 is equal to L_3. With this assumption we may write,

$$T_3=\frac{H}{V_e}+\frac{L_3}{V_r}+\frac{H}{V_e}=\frac{2H}{V_e}+\frac{L_3}{V_r} \tag{6}$$

$$\text{or } H=\frac{V_eT_3}{2}-\frac{V_eL_3}{2V_r} \tag{7}$$

When the distance L_3 is of such value that the direct wave through the earth reaches detector D_3 at the same time as the refracted wave, it is said to be the critical distance and we may write,

$$T_3=\frac{L_3}{V_e}=\frac{2H}{V_e}+\frac{L_3}{V_r} \text{ or}$$

$$H=\frac{L_3}{2}\left(1-\frac{V_e}{V_r}\right) \text{ and}$$

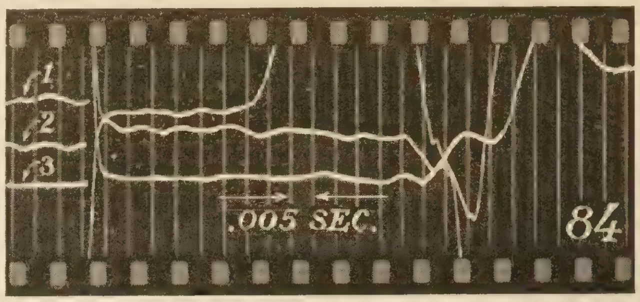
$$L_3=\frac{2H}{1-\frac{V_e}{V_r}} \tag{8}$$

For best results, when determining depths to rock, L should not be greatly in excess of the critical distance. As a fairly close approximation we may say that for values of V_e and V_r usually found, $H=0.45\ L$, or $L=2.2\ H$, where L is the critical shooting distance.

Various modifications of the technique just described are sometimes necessary to determine slopes, domes, and other irregularities in underground structures. The depth to rock, H, as given in equation 7, is really the average of the depth at the shot and that at the detector. By shooting near one end of a line of detectors and then near the other end an estimate of the slope can be obtained. "Circle shooting" is another means of studying subsurface irregularities. With this method two or more detectors are placed on the arc of a circle having a radius greater than the critical distance and the shot is placed at the center. The order in which the waves reach the detectors will indicate the relative rock depths under them, the shorter time indicating the shallower rock.

Equation 5 cannot always be relied upon to give very accurate values of V_r because of the difficulty of obtaining an accurate measure of the time interval T_3-T_2 from the film record. If the detectors are placed 20 feet apart the time interval representing a velocity of 18,000 feet per second in the underlying rock will be only 0.0011 second, or a distance of about 0.0264 inch on a film moving at a speed of 2 feet per second.

It is obvious that slight differences in the performance of different detectors and errors in picking the exact time of breaks on the traces will make it impossible to determine velocities in rock by the use of closely placed detectors. Fortunately, the term in equation 7,



CALCULATION OF DEPTH TO ROCK

SHOOTING DISTANCES, $L_1=50$ FEET, $L_2=100$ FEET, $L_3=150$ FEET.
TIME OF WAVE TRAVEL FROM SHOT TO DETECTORS, $T_1=.0355$ SECOND, $T_2=.071$ SECOND, $T_2=.074$ SECON

V_e = VELOCITY OF WAVE IN EARTH $=\frac{L_1}{T_1}=\frac{50}{.0355}=1{,}400$ FEET PER SECOND.

V_r = VELOCITY OF WAVE IN ROCK $=\frac{L_3-L_2}{T_3-T_2}=\frac{50}{.003}=16{,}700$ FEET PER SECOND.

·, = DEPTH TO ROCK $=\frac{V_e\,T}{2}-\frac{L}{2}\frac{V_e}{V_r}=\frac{1{,}400\times .074}{2}-\frac{150}{2}\times\frac{1{,}400}{16{,}700}=45.5$ FEET.

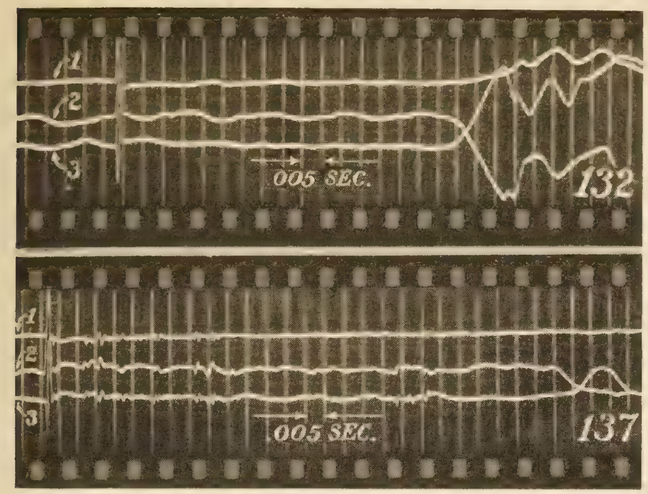
FIGURE 12.—SEISMIC RECORD AND CALCULATIONS BASED ON RECORD.

in which V_r appears, is of minor importance, provided the shooting distance is not greatly in excess of the critical distance. For this reason an average or normal value of V_r, such as 18,000 feet per second may be assumed without fear of carrying through an error of consequence into the final value of H. Equation 7 may be used only when the shooting distance exceeds the critical distance, and this condition can usually be determined from a measure of the time intervals between detectors, even though such intervals may not give highly accurate values of velocities in rock.

FIELD TESTS GIVE SATISFACTORY RESULTS

The accuracy with which H can be determined from equation 7 will depend largely upon the value of V_e selected. In most soils the value of V_e increases with depth and the value to be substituted in the equation must therefore be intermediate between the velocity in the topsoil and that in the deeper strata. Figure 11 shows several velocity-distance curves from which values of V_e were selected in determining rock depths at the locations given. All of the curves show a distinct upward trend after the critical shooting distance is reached or, in other words, when the path of the fastest wave is through rock. At the Boundary Channel Bridge the rock is overlain with about 75 feet of spongy muck or silt and this condition is indicated by the rather flat portion of the curves within the critical distance. The same condition exists at the Bryan statue triangle and at the Memorial Bridge, in both locations the critical distance being approximately 100 feet. From the flat portion of such curves closely accurate values of V_e can be selected and equally accurate values of H obtained.

Figure 12 shows a single record from which the depth of rock at the Memorial Bridge has been calculated. The 3 detectors were spaced respectively 50, 100, and 150 feet from the shot. In this case the critical distance appears to be almost exactly 100 feet. This follows from the fact that calculations based on traces 1 and 2 result in the same velocity, thus indicating that the wave reaching P_2 could have traveled directly through the earth. However, the difference in time intervals T_3 and T_2 is such as to give a velocity of 16,700 feet per second between P_2 and P_3, which is very close to



CALCULATIN OF DEPTH TO ROCK

FROM FILM 132, $L=110$ FEET, $T=.085$ SECOND, $V_e=\frac{L}{T}=1{,}300$ FEET PER SECOND.

FROM FILM 137, $L_2=330$ FEET, $L_3=360$ FEET, $T_2=.135$ SECOND, $T_3=0.1385$ SECOND.

FOR $L=360$ FEET, DEPTH TO ROCK $=H=\frac{V_e T}{2}-\frac{L V_e}{2 V_r}$

$$=\frac{1{,}300}{2}\times .1385-\frac{360\times 1{,}300}{2\times 16{,}700}=90-14.0=76.0 \text{ FEET.}$$

FIGURE 13.—SEISMIC RECORD AND CALCULATIONS BASED ON RECORD.

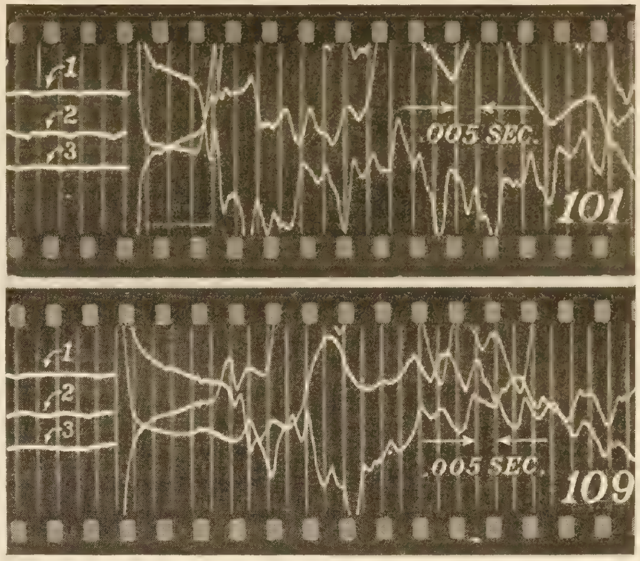
velocity in rock. It is evident, therefore, that the time of travel to the middle detector is the same by either the direct path or the path of the refracted wave through the rock, a condition that determines the critical distance.

Figure 13 shows records from which the depth to rock at the Boundary Channel Bridge was calculated as 76 feet, a figure that checks closely with the bridge engineer's data.

DIFFICULTY SOMETIMES ENCOUNTERED IN MAKING DETERMINATIONS

Frequently the velocity curve will take the form of the curve in figure 11 that is based on tests at the Arlington experiment station. Here the critical distance is not so evident. The method by which a value of V_e was selected and the depth to rock calculated in this location will be given in detail as a typical example of a practical problem. Figure 14 shows some of the records from which depth calculations were made and table 1 is summary of all data obtained. An examination of this table shows that high velocities existed for that portion of wave travel in excess of 50 feet. Because of the very short time intervals involved and the difficulty in picking the exact breaking points on the traces and also as a result of slightly different sensitivities and characteristics in detectors, it is not always possible to obtain accurate velocities for increments in distance from which velocities in rock can be derived. It is possible, however, as in this case, to determine from the velocities if the movement is through rock and also to approximate the critical distance.

The high velocities for that portion of the travel through increments in distance at more than 50 feet from the shot enables us to select 50 feet tentatively as the critical distance. By averaging all of the over-all velocities for distances of 50 feet and less, a value of 1,834 feet per second is obtained. This is so close to the value of



CALCULATION OF DEPTH TO ROCK

FROM FILM 101, $L_1=L_2=L_3=30$ FEET, $T=0.0165$ SECOND, $V_e=\frac{L}{T}=1{,}820$ FEET PER SECOND.

FROM FILM 109, $L_1=120$ FEET, $L_2=150$ FEET, $L_3=180$ FEET, $T_1=0.0255$ SECOND, $T_2=0.029$ SECOND, $T_3=0.0325$ SECOND, FOR $L=150$ FEET.

DEPTH TO ROCK $=H=\frac{V_e T}{2}-\frac{L V_e}{2 V_r}=\frac{1{,}820}{2}\times 0.029-75\times\frac{1{,}820}{16{,}700}=17.2$ FEET.

FIGURE 14.—SEISMIC RECORD AND CALCULATIONS BASED ON RECORD.

TABLE 1.—*Results of tests at the Arlington experiment station*

Record no.	Shooting distance, L	Time of wave travel, T	Overall velocity, V	Velocities for increments in distance, equation 5	Depth to rock H, from equation 7
	Feet	*Seconds*	*Feet per second*	*Feet* — *Feet per second*	*Feet*
97	10	0.0065	1,540	10 to 20 = 1,540	
99	20	.013	1,540	20 to 30 = 2,860	
101	30	.0165	1,820	30 to 40 = 2,860	
104	40	.02	2,000	40 to 50 = 5,000	
106	50	.022	2,270	50 to 60 = 20,000	
107	60	.0225	2,670	60 to 100 = 8,900	17.2
100	100	.027	3,700	100 to 120 = Infinite	19.2
109	120	.0255	4,700	100 to 150 = 25,000	16.7
109	150	.029	5,000	100 to 180 = 10,700	18.2
109	180	.0325	5,450	60 to 180 = 12.000	19.8
Average					18.22

1,820 feet per second derived directly from record no. 101 for a 30-foot distance that the latter was selected for V_e. Since the values of velocities corresponding to increments in distance shown in table 1 are not sufficiently consistent to justify a selection of V_r from them, a value of 16,700 is taken as fairly representative of velocity in rock. As pointed out previously, this value enters into only a minor term in the depth equation and therefore great accuracy is not so necessary in its determination as in that of V_e. With these values of V_e and V_r the value of H was computed for all distances in excess of 50 feet. The results appear in the last column of table 1, the average of which is 18.22 feet. The actual depth to rock as determined with a soil auger is 19.8 feet.

Sometimes it is necessary to make a first approximation of the depth to rock, after which a more accurate value of V_e can be selected from the velocity curve. In any event, no great error will be made in selecting a value of V_e, which is an average of all values obtained under the critical distance.

(Continued on p. 74)

EXTRACTS FROM REPORT ON FLORIDA TRAFFIC SURVEY

CHARACTERISTICS OF TOURIST TRAFFIC AND TRANSPORTATION OF CITRUS FRUIT DISCUSSED

Reported by L. E. PEABODY, Senior Highway Economist, Division of Highway Transport

A SURVEY OF TRAFFIC on Florida State highways was conducted by the Florida State Road Department and the Bureau of Public Roads, from September 1933 to September 1934. Data were collected at 157 points in the State.[1]

The traffic on Florida highways was found to have characteristics distinct from the traffic in most States. The month of largest traffic volume is January, and September is the month of least motor travel. Seasonal variation is of small amplitude in comparison with that in many States. There is an absence of large volumes of industrial traffic; truck capacities are generally low; and tourist traffic is an important component of total motor traffic.

Seven percent of the mileage of the State highway system carries a traffic volume in excess of 1,500 motor vehicles per day; 41 percent carries a volume of from 500 to 1,499 vehicles per day; and more than half of the State highway mileage carries less than 500 vehicles per day.

Seventy-eight and two-tenths percent of the observed vehicles were passenger cars; 21.0 percent were trucks; and 0.8 percent were busses. Local vehicles, which constituted 80.3 percent of the total traffic, were distributed as follows: Passenger cars, 76.1 percent; trucks, 22.9 percent; and busses, 1.0 percent. Trucks with trailers were 5.4 percent of all trucks, four-tenths of 1 percent being foreign and the remainder were local.

Distances are long and population is concentrated within a few areas. Traffic volumes are relatively high close to the population centers and are fairly uniform between population centers. Major routes may be easily identified on the traffic-flow maps. Figure 1 shows total traffic and figure 2 shows foreign traffic. The main routes are: U S 92 from Daytona Beach to the intersection with U S 17 and from Haines City to Tampa, and Florida 64 from Tampa to St. Petersburg; U S 1 and Florida 4–A from the Georgia State line to Florida City; U S 17 from the Georgia State line to Punta Gorda; U S 90 from the Alabama State line to Jacksonville; and U S 19 from Brooksville to St. Petersburg. The routes carrying the most foreign traffic are U S 1 from the Georgia State line to Miami, Florida 64 from Tampa to St. Petersburg, U S 41 together with Florida 5 and U S 541 from the Georgia State line to Naples, and U S 92 from Daytona Beach to Tampa.

Florida's traffic history since 1925, as shown by traffic counts at 22 stations since that year, is very different from that of any other State for which data are available. This statement may be illustrated most briefly by two examples. Between 1922 and 1933 motor vehicle registration increased 140 percent in Florida and 147 percent in New Jersey; yet between 1922 and 1926 the corresponding increases were 246 percent in Florida and 90 percent in New Jersey. And again, gasoline consumption increased 228 percent in Connecticut between 1922 and 1933, as compared with 220 percent in Florida during the same period. However, gasoline consumption increases in Connecticut and Florida between 1922 and 1926 were 83 and 350 percent respectively. In view of the above it is remarkable that Florida traffic in 1932 had declined but 28 percent from its all-time peak in 1926. The first indication of a possible reversal of the downward trend in motor-vehicle registration since 1927 is given in 1934, when registration increased 20 percent over the previous year. Gasoline consumption in 1934 was more than 14 percent greater than in 1933.

[1] The complete report is being published by the Florida State Road Department, Tallahassee, Fla. Copies are not available from the Bureau of Public Roads.

TOURIST TRAFFIC ORIGINATES IN MANY STATES

Tourist traffic is smallest in May, but even in that month amounts to 70 percent of the monthly average. The common impression that tourist traffic is confined to the period of winter is incorrect; although, of course, the volume is much heavier during that period.

Nearly a quarter of the tourist traffic, excluding the traffic of tourists who spend less than 1 day in Florida, comes from that portion of the United States east of the Mississippi and north of the Potomac and Ohio Rivers. The origin of tourist traffic is shown in figure 3 in which the volume of tourist traffic originating in the areas indicated is proportional to the area of the circle shown in each area. The average travel of this group of tourists to and from their homes is in excess of 2,000 miles. More than one-half of all tourists in Florida are from Georgia and Alabama, again excluding those who spend less than 1 day within the State. More than 10 percent come from the States of Michigan, Wisconsin, Illinois, Indiana, and Ohio. The remaining tourists, approximately 20 percent, have origins scattered throughout the remainder of the country.

They stay in Florida about 1 month on the average, although there is high variation in the length of stay. Tourists who own homes in Florida make an average visit of 106 days, while those who stay with friends or relatives remain about 2 weeks. Those who rent apartments or cottages stay about 88 days; visitors who stop at hotels stay an average of 20 days; while those who occupy camps average 34 days per visit.

About 11 percent of the tourists stated that they would visit areas throughout the whole State, their answers reading typically: "Throughout the State", "everywhere in the State", "all over Florida", etc. The southeast section of Florida was the greatest attraction, nearly one-quarter of all tourists planning to visit that area.

The general routes of travel to Florida are indicated by bands of varying width in figure 3, the width representing the volume of traffic. These bands do not follow the exact location of any single route, and the traffic on two or more closely parallel routes may be shown by a single band. The increments of traffic received from each area of origin are indicated by the

Figure 1.—Average Daily Motor Vehicle Traffic on Florida Highways, 1934.

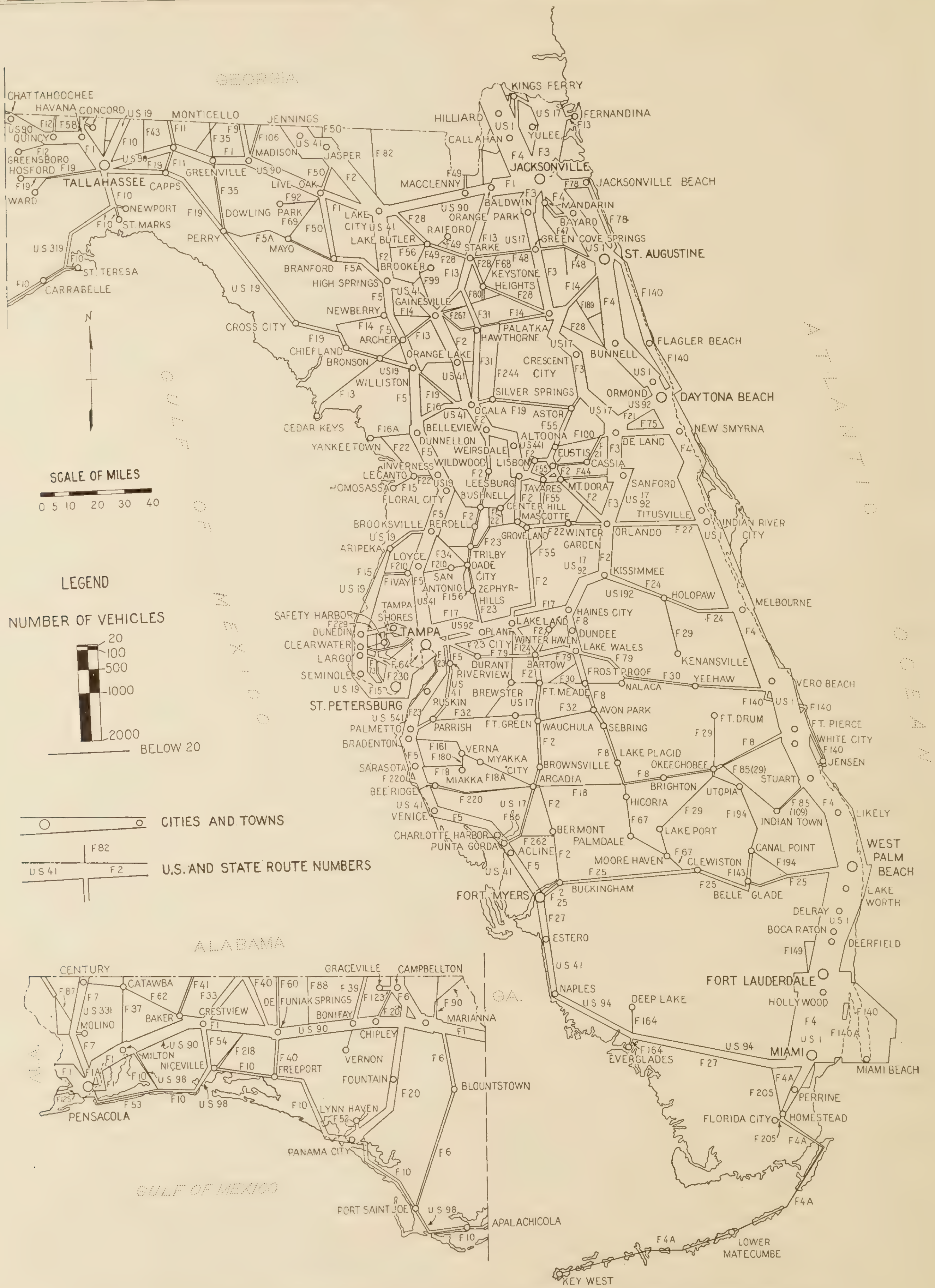


FIGURE 2.—AVERAGE DAILY TRAFFIC BY FOREIGN VEHICLES ON FLORIDA HIGHWAYS, 1934.

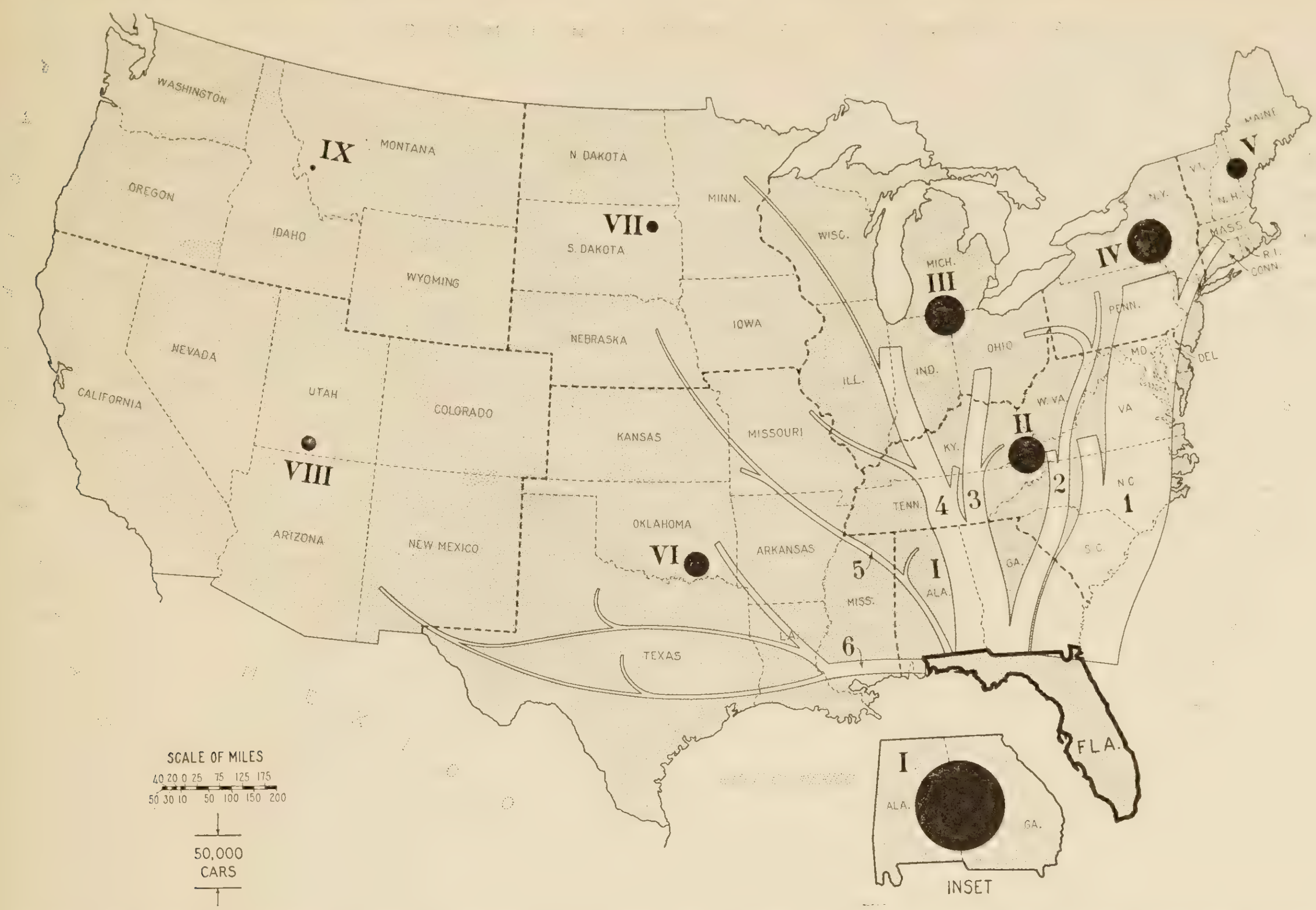


FIGURE 3.—ORIGIN OF MOTOR TOURIST TRAFFIC TO FLORIDA AND LINES OF TRAVEL. SIZE OF CIRCLE INDICATES RELATIVE NUMBER OF TOURISTS FROM EACH AREA, AND WIDTH OF BAND INDICATES THE RELATIVE VOLUME OF TRAFFIC USING EACH LINE OF TRAVEL.

increase in width of a band as it passes through that area. The traffic from area I is omitted because the volume is so large and the routes of travel are so short that an adequate graphical comparison with other areas is impossible. The preponderance of travel on the eastern coastal routes is apparent by the relative width of band 1. The principal routes included within this band are U S routes 1, 15, and 17. By far the greatest part of the traffic traveling these routes originates in New York, New Jersey, and Pennsylvania, with considerable increments from New England and from area II.

A less-popular line of travel from these same areas is indicated by band 2, which represents principally the traffic on eastern inland routes, United States routes 11, 19, 21, 29, and 41. Most of the traffic following this line originates in area II, but there is a considerable amount from area III, and an appreciable increment from area IV.

The most popular lines of travel from area III are indicated by bands 3 and 4, band 3 joining band 4 at the Georgia State line. Band 3 represents United States routes 25 and 27; and band 4 represents United States routes 31 and 41. Bands 5 and 6 indicate the lines of travel from the States west of the Mississippi River.

Contrary to what is probably the popular impression, those who gave "business" as their reason for visiting Florida constituted the largest group classified. Many people combined their business with a fishing trip, visited friends or relatives in Florida, attended sporting events, or were en route to other States.

A classification of tourist parties by type of accommodation shows that the greatest number used hotels. In this class were 162,590 parties, or 38.9 percent of the 417,960 parties staying one day or more in Florida. The next largest group, 21.0 percent, stayed with friends or relatives, 9.9 percent stopped at tourist homes, and 10.9 percent used more than one type of accommodation. These four major groups comprise four-fifths of the total. The 97,040 parties staying less than one day comprise 18.8 percent of the grand total of 515,000 parties per year.

LARGE EXPENDITURES MADE BY TOURISTS

Data with regard to the expenditures of tourists were obtained by a special investigator. Tourists were questioned as to the daily expenditure per party at times and places where they could be approached conveniently and with ample time for the investigator to satisfy himself with regard to the accuracy of the replies. The information was voluntarily given and was subject to critical questioning at the time by the investigator. Expenditures were tabulated under the general heads of "car expenses" and "other expenses." Separated under "car expenses" were the costs of gasoline, oil, garaging, and repairs incurred only during the visit. Overhead items, such as depreciation and insurance, that were not likely to be a direct expenditure in Florida, were not considered. Under "other expenses" were tabulated the items of food, lodging, and miscellaneous expenditures.

From the data obtained in this manner it was possible to compute the average party expenditures per day according to type of accommodation as presented in table 1. With the exceptions noted, these are the averages of expense items as given by a large number of separate parties, and considerable effort was made both in collecting the data and in the analysis to eliminate error and exaggeration. The replies by persons staying with friends and relatives and those using a combination of accommodations were so few in number as to throw doubt upon the correctness of average expenditures based upon them. Therefore, the expenditures tabulated for these groups were obtained by averaging appropriate items in other groups that were considered similar in characteristics. Expenditures by those staying one day were estimated in like manner as no replies were received from persons in this class.

TABLE 1.—*Itemized expenditures per party per day according to type of accommodation*

Item	Hotels	Rented cottages or apartments	Tourist homes	Camps	Own home	Friends and relatives	Combination	Less than 1 day
Persons per party	2.28	2.95	2.83	3.28	2.84	3.09	2.87	2.60
Average daily mileage per car	24	22	19	22	22	-------	-------	------
Cost of car operation per day:								
Gasoline	$0.36	$0.32	$0.26	$0.32	$0.36	-------	-------	------
Oil	.04	.03	.03	.03	.04	-------	-------	------
Garaging	.23	.02	.02	------	------	-------	-------	------
Repairs	.01	.02	.01	.01	.02	-------	-------	------
Total	.64	.40	.32	.36	.42	[1] $0.54	[1] $0.54	[1] $0.54
Other expenditures per party per day:								
Lodging	3.66	1.39	1.12	.35	3.75	-------	-------	------
Food	3.18	1.90	2.46	1.22	2.39	[2] 2.15	-------	[1] 2.23
Miscellaneous	1.33	.97	.56	.70	1.61	[1] 1.03	-------	[1] 1.03
Total	8.17	4.25	4.14	2.27	7.75	3.18	5.32	3.26
Total expenditures per party per day	8.81	4.65	4.46	2.63	8.17	3.72	5.86	3.80

[1] Average of other types.
[2] Average of food costs for those using "rented apartments" and "own home."

The daily lodging cost to parties staying at their own homes, as shown in table 1, is the estimated daily rental value of such homes. The figure, $3.75, is based upon an average value of $6,000 per home as given by the questionnaires and annual operating costs and carrying charges are assumed to equal 10 percent of value, or $600 annually. This sum is charged against a season of 160 days, or $3.75 per day.

On the basis of total daily expenditures, the two most important groups are those using hotels and home owners. Parties in these groups expended $8.81 and $8.17 per day, respectively. The parties spending the least amounts were those staying with friends and relatives, $3.72 per party per day, and the campers with an average expenditure of only $2.63 per party per day.

The information concerning type of accommodation, volume of traffic of each type, length of stay, and daily expenditures has been combined to estimate the total yearly expenditures within the State. The estimate is presented in table 2. The number of parties per year and the average length of stay for each group are shown in columns 2 and 3. The daily average party costs are repeated from table 1 in column 4. The estimate of the total yearly expenditures by each group of tourists is given in the last column. The total by all groups is $90,458,000; thus tourists are an impressive source of income to the State.

TABLE 2.—*Estimate of tourist expenditures by type of accommodation*

Stopping at—	Total cars per year	Average length of stay in days	Average cost per party per day	Expenditures per year	Percentage of total expenditures
Hotels	162,590	19.5	$8.81	$27,932,000	30.87
Apartments and cottages	22,150	87.7	4.65	9,033,000	9.98
Tourist homes	41,380	48.2	4.46	8,896,000	9.83
Camps	26,330	33.5	2.63	2,320,000	2.57
Own home	32,180	106.3	8.17	27,947,000	30.89
Friends and relatives	87,770	16.1	3.72	5,257,000	5.81
Combinations	45,560	32.6	5.86	8,704,000	9.62
Less than 1 day	97,040	----------	3.80	369,000	.43
Total	515,000	----------	----------	90,458,000	100.00

Tourists using hotels and those staying at their own homes are estimated to spend the largest amounts. The expenditures of each of these groups are nearly $28,000,000 per year, and between them they account for 62 percent, or nearly two-thirds, of the total sum spent by all tourists, and yet the number of tourists using their own homes is only 7.7 percent of all tourists. In contrast, those staying with friends are 21 percent of the total number, but their expenditures represent only 5.8 percent of the total expenditures. The contrast is even more striking in the case of trips of less than 1 day. Although 18.8 percent of the total number, they account for less than one-half of 1 percent of the total expenditure.

Table 3 gives an estimate of the direct income to the State government from tourist traffic in the form of gasoline taxes. On the average, each tourist car travels about 1,000 miles in Florida during the visit, or 515,000,000 miles for the total traffic. At 14 miles per gallon, 36,786,000 gallons of gasoline are consumed, yielding $2,575,000 at the current tax rate of 7 cents per gallon, and equivalent to approximately 16 percent of all State gasoline taxes.

TABLE 3.—*Estimate of total yearly mileage of tourist cars in Florida and payments of gasoline tax*

Average miles per car per day	22
Average length of stay per car in days	29.4
Total mileage per car per visit	647
Travel in Florida to and from destination, miles	392
Total mileage per car (round figures)	1,000
Total yearly traffic	515,000
Total yearly mileage	515,000,000
Estimated miles per gallon of gasoline	14.0
Total gallons of gasoline consumed	36,786,000
Tax per gallon	$0.07
Total tax paid by tourists	$2,575,000

TRUCK SHIPMENTS OF CITRUS FRUIT NUMEROUS

Citrus fruits, with a net farm value of approximately $37,000,000 in 1933–34, originate in an area south of a line from Palatka to Cedar Keys, largely from the sections surrounding Orlando and Leesburg, and from Sebring to Lakeland. During the season of 1933–34 the interstate truck shipments aggregated 31,590 truck

FIGURE 4.—DISTRIBUTION OF FLORIDA CITRUS FRUITS BY STATES; ANNUAL TRUCK SHIPMENTS ON LARGE-SCALE MAP AND RAIL SHIPMENTS SHOWN ON SMALL-SCALE MAP.

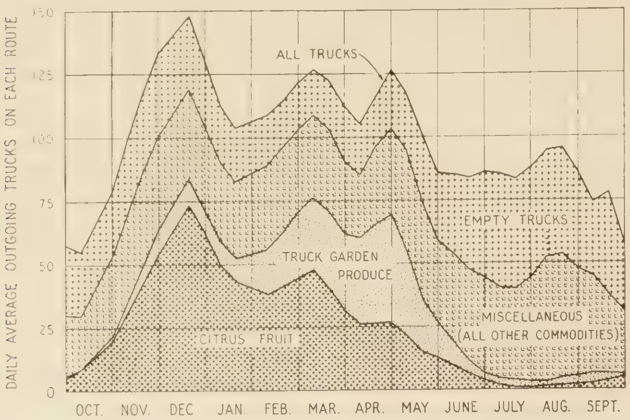


Figure 5.—Seasonal Movement of All Outgoing Trucks on the Principal Commercial Interstate Routes U S 1, U S 17, and U S 41.

loads. These truck shipments were destined mainly to Georgia, South Carolina, Alabama, North Carolina, Tennessee, the District of Columbia, and Virginia (see fig. 4), with the number of trucks in the above order. The States enumerated took about 88 percent of the total interstate truck shipments. In the total movement, all States east of the Mississippi River except the New England group and Delaware were represented, while west of the Mississippi only the States of Missouri, Arkansas, Texas, and Louisiana received truck loads of citrus fruits from Florida. Georgia and South Carolina accounted for more than half the total interstate citrus fruit shipments by truck.

The peak of the truck movement of citrus fruits is in mid-December, with a secondary peak near the middle of March. After the bulk of the fruit had been moved, many of the truckers shifted to the transportation of garden produce—beans, tomatoes, asparagus, etc.

Fifteen percent of the 215,600 outgoing trucks crossing the Florida State line during the year carried citrus fruits; 8 percent carried garden produce; 40 percent carried miscellaneous commodities; and 37 percent were empty. Figure 5 indicates the seasonal movement of these trucks and the shifting from citrus fruit hauling to the transportation of garden produce.

U S 1, U S 17, and U S 41 were the major gateways through which these commodities moved, these three routes together carrying 82 percent of all citrus fruit shipped to other States by truck and 82 percent of the interstate garden-produce shipments.

More than 80 percent of all trucks crossing the State border and carrying citrus fruit was registered in States other than Florida. Seventy-one percent of trucks carrying garden produce in interstate commerce was also registered in other States.

Fifty-two percent of all trucks used in the carrying of citrus fruit had capacities of 2 to 4 tons; 40.5 percent were in excess of 4 tons; while 7.5 percent had capacities up to and including 1½ tons. The use of trailers was negligible, since less than 2 percent of all trucks hauled trailers.

The internal movement of citrus fruit was largely to packing plants and canneries at Tampa and Jacksonville.

(Continued from p. 67)

The velocity curve obtained at Williamsburg, Va., figure 11, applies to a marl and shell conglomerate overlain by a few feet of clay. The velocities found are relatively high for a location where there is no rock near the surface and are the result of the highly compacted shell conglomerate which appears to have about the same acoustical properties as a deep clay or shale.

A few tests have been made at quarry sites and at other locations where solid rock is found within a few feet of the ground surface and all indicate that the depth of such overburdens can be determined quickly, definitely, and accurately by the seismic method. For such work a single no. 8 blasting cap gives ample energy, thus reducing the cost of explosives to a negligible amount.

While the work of the bureau with the seismograph has been largely experimental and limited to one locality, the results to date have been so promising that they leave little doubt as to the ultimate value of this tool in the study of subsurface formations.

LITERATURE CITED

(1) Gish, O. H.
1926. IMPROVED EQUIPMENT FOR MEASURING EARTH-CURRENT POTENTIALS AND EARTH RESISTIVITY. National Research Council Bulletin, Vol. 11, No. 56.

(2) Kurtenacher, K. S.
1934. SOME PRACTICAL APPLICATIONS OF RESISTIVITY MEASUREMENTS TO HIGHWAY PROBLEMS. Transactions, American Institute of Mining and Meteorological Engineering, Vol. 110, No. 49. (Also reported to the Mississippi Valley Conference of Highway Departments.)

(3) Kurtenacher, K. S.
1934. USE OF RESISTIVITY METHODS FOR LOCATING AND EXPLORING DEPOSITS OF STONE AND GRAVEL. Rock Products, July, p. 32.

(4) Lee, F. W.
1928. MEASURING THE VARIATION OF GROUND RESISTIVITY WITH A MEGGER. U. S. Dept. of Commerce, Bureau of Mines, Technical Paper 440.

(5) Lee, F. W., Joyce, J. W., and Boyer, Phil.
1929. SOME EARTH RESISTIVITY MEASUREMENTS. U. S. Dept. of Commerce, Bureau of Mines, Information Circular 6171.

(6) Lee, F. W., and Swartz, J. H.
1930. RESISTIVITY MEASUREMENTS OF OIL-BEARING BEDS. U. S. Dept. of Commerce, Bureau of Mines, Technical Paper 488.

(7) McCollum, Burton.
1921. MEASURMENTS OF EARTH CURRENTS. Electric Railway Journal, Nov. 5.

(8) Schappler, R. C., and Farnham, F. C.
1933. THE EARTH RESISTIVITY METHOD APPLIED TO THE PREDICTION OF MATERIALS IN EXCAVATION. Paper presented at the Twenty-fifth Mississippi Valley Conference of State Highway Departments at Chicago, February.

(9) Swartz, J. H.
1932. OIL PROSPECTING IN KENTUCKY BY RESISTIVITY METHODS. U. S. Dept. of Commerce, Bureau of Mines, Technical Paper 521.

(10) Tagg, G. F.
1932. INTERPRETATION OF RESISTIVITY MEASUREMENTS. American Institute of Mining and Meteorological Engineering, Technical Publication 477.

(11) Wenner, Frank.
1915. METHOD OF MEASURING EARTH RESISTIVITY. U. S. Dept. of Commerce, Bureau of Standards, Scientific Paper 258.

(12) Wilcox, Stanley W.
1935. PROSPECTING FOR ROAD MATERIAL BY GEOPHYSICS. Engineering News-Record, Feb. 21, p. 271.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF MAY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$3,947,753	$2,129,921	$5,910,559	$3,207,195	$35,889	321.6	$2,469,521	$689,465	$1,235,363	142.7	$35,462	$283,727	13.7	$15,632	$574,942
Arizona	3,878,555	1,338,712	4,813,746	3,741,188	410,963	335.7	1,070,577	99,279	867,223	59.3		51,395		38,088	9,131
Arkansas	3,334,167	1,714,000	3,204,323	2,497,443	182,638	157.1	1,998,007	658,284	1,025,049	86.7	158,919	203,155	28.2	19,521	303,159
California	7,912,928	3,713,643	9,850,132	7,198,859	160,700	294.2	4,086,820	712,709	2,223,795	124.6		696,073	24.5	1,360	633,075
Colorado	3,437,265	2,424,504	4,310,032	3,321,549	879,368	210.5	1,745,017	110,498	1,527,416	76.6				5,218	17,720
Connecticut	1,404,213	607,500	797,613	795,279		14.5	1,451,228	608,934	579,726	23.4					27,774
Delaware	877,566	461,697	1,052,958	868,470	177,572	42.1	292,719	4,973	274,892	6.8	4,082	7,442		40	1,792
Florida	2,469,370	1,116,600	3,079,015	2,211,915	61,384	117.9	973,060	191,660	731,244	33.8	17,087	99,228	4.1	48,707	224,743
Georgia	5,045,592	2,556,745	4,112,681	3,620,465	255,697	290.8	2,605,165	1,280,056	1,242,086	128.0	6,394	332,032	9.8	138,678	726,930
Idaho	2,166,858	1,131,910	2,072,442	1,967,735	35,916	183.0	783,026	192,495	577,668	48.8				6,628	518,326
Illinois	4,408,827	2,408,778	2,203,523	2,141,079	19,269	38.6	4,030,041	2,254,193	1,775,848	66.3	3,000	414,494	2.8	10,555	199,167
Indiana	5,918,921	2,816,687	3,494,046	3,396,228		111.4	3,328,565	1,496,941	1,796,409	144.7	77,951	931,062	42.4	47,801	89,216
Iowa	5,027,830	2,217,361	4,801,249	4,637,430	78,520	288.6	2,657,630	390,400	2,021,869	146.2		66,260	4.6		50,712
Kansas	5,044,802	2,354,131	5,649,117	4,949,300	564,871	609.3	1,898,343	86,912	1,743,637	152.8		45,623	1.7	8,590	
Kentucky	3,751,605	1,302,209	3,594,656	3,314,189	33,571	243.6	1,025,867	384,396	565,267	82.9		552,258	21.9	53,020	151,113
Louisiana	2,693,135	1,380,419	2,685,146	2,296,812	19,599	76.6	1,600,583	343,350	1,103,969	28.1	36,405	17,157	1.3	16,568	239,694
Maine	1,567,012	782,195	1,351,182	1,310,906	10,497	44.3	796,215	248,494	547,721	12.9		223,977	7.1	7,612	
Maryland	1,782,263	289,609	862,107	791,495	70,360	15.5	948,151	797,232	150,919	21.3				193,536	68,330
Massachusetts	1,101,716	1,632,874	1,425,641	1,032,666		37.4	937,996	52,687	833,487	12.5		162,525	7.7	16,363	636,862
Michigan	6,051,532	3,226,284	4,988,486	4,719,527	81,400	225.1	3,680,300	1,284,500	2,381,000	146.0		554,275	26.3	47,506	209,609
Minnesota	4,561,011	2,642,244	5,707,670	4,241,696	1,308,545	905.0	946,579	179,056	748,922	120.9	67,882	316,705	45.8	72,377	268,071
Mississippi	3,489,337	2,832,182	4,814,705	2,470,565	298,408	248.0	2,892,110	849,964	1,354,716	157.6	124,882	728,687	49.6	43,925	450,370
Missouri	5,237,532	2,132,426	4,748,082	4,209,249		189.8	3,034,479	950,949	1,855,140	92.8		277,286	12.2	77,334	
Montana	4,463,849	2,714,208	6,073,696	4,459,720	1,116,367	509.0	1,499,590	4,129	1,393,384	127.1		189,850	.2		14,606
Nebraska	3,914,481	1,982,182	5,148,343	3,875,799	137,284	369.4	2,111,098	25,639	1,730,423	100.2		42,563	5.1	13,043	71,913
Nevada	2,909,387	1,350,356	3,172,505	2,668,146	433,021	302.7	876,158	202,644	672,847	119.4	17,735	14,755	2.6	20,863	229,733
New Hampshire	692,119	465,404	638,684	612,389		10.8	542,872	79,730	441,404	12.5					24,000
New Jersey	3,173,019	951,379	1,757,402	1,733,583		31.6	1,973,510	1,405,336	330,958	18.7		269,816	2.3	34,100	350,605
New Mexico	2,846,648	1,676,769	3,501,414	2,760,948	596,536	344.4	963,212	85,700	806,618	64.8					273,615
New York	10,465,672	3,748,600	10,599,201	8,686,358	181,330	214.4	8,532,593	1,630,019	3,313,880	146.9		48,500		149,295	204,890
North Carolina	4,761,147	1,930,365	4,809,411	3,499,965	382,833	590.0	1,418,881	873,383	356,624	158.5	139,906	463,108	23.5	247,893	727,799
North Dakota	2,902,224	1,469,484	3,203,886	2,617,060	139,940	1,064.5	635,579	59,883	406,526	239.8	65,660	248,512	132.1	159,620	674,505
Ohio	7,277,758	3,539,256	7,447,532	7,040,880	16,500	191.4	3,397,860	131,720	2,924,090	71.7	102,798	8,720	1.9	2,360	589,946
Oklahoma	4,608,399	2,342,590	4,593,178	4,098,690	361,341	311.6	2,033,637	498,548	1,322,575	83.2	10,032	520,949	22.9	1,130	137,725
Oregon	3,053,448	1,452,741	3,599,415	2,964,300	279,947	193.9	1,169,203	80,590	988,992	49.5		114,860	5.8	8,558	68,942
Pennsylvania	6,691,194	4,554,082	6,414,620	5,716,391	431,666	132.8	5,018,561	915,718	3,882,969	87.1	2,126	42,824	1.1	56,959	196,623
Rhode Island	979,367	474,772	968,005	899,627		20.5	560,592	79,740	464,572	14.3					10,200
South Carolina	2,729,583	940,954	2,398,609	2,260,483	73,571	204.5	763,691	374,583	389,108	66.2	58,706	27,998	2.4	35,811	450,277
South Dakota	3,005,739	1,523,821	2,804,444	2,236,171	90,724	477.8	1,332,729	598,726	719,345	257.4	113,454	592,081	93.7	57,389	121,672
Tennessee	4,246,309	2,105,453	4,827,144	4,001,356	184,679	189.0	1,454,956	176,547	1,182,008	46.8	9,488	556,213	20.2	58,917	182,554
Texas	11,588,643	6,858,253	12,030,113	11,143,481	324,664	1,043.8	5,646,433	389,255	5,057,564	424.3	39,890	494,338	41.0	16,017	981,687
Utah	2,367,205	1,066,345	3,014,382	2,324,852	476,525	258.5	637,029	37,000	437,550	44.5				5,353	152,271
Vermont	928,184	466,042	980,688	911,663	28,464	47.9	381,556	10,670	342,862	17.5		80,224	2.2	5,851	14,492
Virginia	3,731,207	1,916,178	3,875,327	3,367,890	263,498	160.9	1,634,505	225,730	1,288,777	68.0	111,491	286,762	25.9	26,096	77,141
Washington	3,057,934	1,553,206	2,880,403	2,620,512	198,794	101.0	1,676,270	402,011	1,153,679	28.4		63,666	.6	35,411	137,067
West Virginia	2,013,405	1,140,167	1,933,571	1,847,329	60,892	71.2	716,607	111,669	588,046	25.4	44,371	120,840	4.7	10,036	370,389
Wisconsin	4,697,518	1,818,970	4,454,970	4,108,641	108,084	211.6	1,720,357	571,758	1,141,389	75.3	182	525,799	20.2	16,937	43,698
Wyoming	2,250,663	1,686,368	2,593,040	2,064,553	365,110	507.9	1,326,472	182,391	1,117,914	204.6		155,540	20.4	3,718	47,804
District of Columbia															
Hawaii	1,693,344	598,778	842,001	526,724		19.3	1,334,240	1,155,109		20.3				11,511	598,778
TOTALS	185,258,236	93,539,354	190,091,095	157,988,751	10,936,937	12,581.0	94,610,190	24,175,655	59,617,470	4,488.1	1,247,903	10,831,279	732.5	1,845,927	12,153,668

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF MAY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 1,805,744	$ 1,723,041	$ 81,263	43.2	$ 831,673	$ 623,453	$ 208,220	27.8	$ 29,878	$ 141,553	2.3	$ 13,555	$ 633,924
Arizona	807,982	305,191	660,221	607,495	37,305	13.5	73,734	20,000	49,172	1.1	129,322	46,328	.4	51,165	172,386
Arkansas	1,964,534	857,025	1,740,924	1,602,739	38,070	43.5	543,041	248,967	292,772	9.5	101,076	243,955	6.0	11,752	282,228
California	4,213,986	2,219,360	4,287,179	3,459,880	235,750	53.8	2,411,082	739,196	1,363,382	16.9		448,244	3.6	14,909	171,984
Colorado	1,718,633	190,000	1,789,097	1,676,118	19,122	37.1	150,288		150,288	2.9				42,515	20,589
Connecticut	802,407	426,500	839,791	802,407	9,448	10.2	137,740		137,740	1.2		143,909	1.7		135,403
Delaware	460,409	230,849	513,762	460,282	44,973	7.2	19,786		19,786	.6		25,019	1.3	127	141,072
Florida	1,459,648	501,200	1,831,478	1,432,802	102,827	21.4	36,542		36,542	.4	2,898	118,227	1.0	23,948	243,604
Georgia	2,724,620	1,278,373	1,661,049	1,628,661		61.2	1,219,848	880,012	332,848	27.0		273,610	6.0	215,946	671,915
Idaho	1,197,829	321,126	1,156,126	1,110,647	2,643	19.4	260,483	45,372	213,923	2.0				41,810	104,560
Illinois	7,381,910	2,230,350	6,416,149	6,122,778		66.4	2,045,568	1,202,054	843,514	8.4	47,260	826,271	5.9	9,819	560,564
Indiana	4,287,050	2,136,306	3,157,872	3,034,021		63.6	1,648,669	1,073,165	573,040	19.7	148,115	1,250,478	20.8	31,750	312,789
Iowa	2,614,472	1,311,000	2,031,920	1,891,868	58,385	54.9	1,401,252	721,565	591,315	21.1	1,000	236,235	6.0	39	425,065
Kansas	2,522,401	1,432,949	2,596,805	2,368,811	69,641	40.4	1,385,846	105,232	1,265,311	15.3	48,358	97,997	2.6		
Kentucky	1,927,828	958,599	1,416,588	1,359,618	6,477	31.9	910,129	525,577	374,701	10.1	30,000	209,802	3.8	12,634	367,619
Louisiana	1,708,577	744,560	738,751	702,860	34,048	19.0	1,227,120	921,988	263,091	17.2	78,986	202,426	3.7	4,742	244,996
Maine	960,426	484,379	835,187	828,794		16.4	146,823	47,071	99,752	1.2	83,948	287,118	4.7	613	97,509
Maryland	891,132	452,515	390,127	384,134		4.1	1,075,978	262,457		.9				244,541	452,515
Massachusetts	5,007,199	847,600	2,143,777	2,102,233		13.4	3,131,554	2,876,372	230,206	5.8		38,077	.7	28,595	579,317
Michigan	3,500,638	1,613,142	3,275,133	3,051,933	104,400	38.8	1,657,700	412,750	1,207,050	14.8	14,950	105,950	4.5	21,005	195,742
Minnesota	3,719,143	1,421,494	3,337,320	3,056,375	232,957	109.9	1,174,799	594,748	485,569	17.5	7,446	23,172	2.4	60,574	679,796
Mississippi	1,744,669	354,022	911,650	853,044	45,338	28.5	967,675	750,135	142,478	27.4	75,757	49,444	4.8	65,734	116,762
Missouri	4,019,501	1,617,451	2,932,657	2,842,548	18,791	51.6	1,241,575	1,038,609	157,129	11.5		63,870	2.5	138,345	1,377,661
Montana	1,115,962	113,092	1,055,202	1,025,115	19,551	33.2	87,990	34,716	28,720	5.1	52,838	24,534	5.2	3,292	40,287
Nebraska	1,957,240	991,091	2,246,830	1,936,925	277,481	39.9	576,603		576,603	9.8		385		20,314	136,621
Nevada	500,051	100,000	479,800	473,901		9.4	57,842		57,842	1.4				26,150	42,158
New Hampshire	740,335	242,465	721,984	668,776	49,851	15.9	131,823	71,559	60,055	3.0		50,935	.3		81,624
New Jersey	3,117,921	1,809,500	2,495,361	2,370,700		21.4	1,440,610	641,265	637,318	6.6		112,071		105,956	1,060,111
New Mexico	1,674,158	529,506	1,646,988	1,466,891	180,097	39.0	192,758	123,326	69,432	2.9	4,129			79,812	279,977
New York	8,255,661	3,756,621	6,998,680	6,355,868	299,400	56.0	4,975,591	1,707,167	3,049,290	30.2	109,000	56,000		83,626	351,931
North Carolina	2,380,573	1,210,236	2,385,032	2,131,966	245,003	82.9	749,064	124,691	585,870	22.1	91,217	240,487	4.3	32,699	138,876
North Dakota	1,451,112	734,741	1,026,608	1,018,678	488	43.5	356,678	228,144	128,534	13.9	178,323	207,424	23.3	25,967	398,296
Ohio	4,335,686	2,359,503	4,508,267	4,014,713	19,045	57.8	1,977,700	226,500	1,624,800	21.7	93,352	259,500	3.2	1,121	456,158
Oklahoma	2,304,200	1,171,295	2,031,211	1,868,393	90,980	43.0	970,052	398,185	568,682	13.0	35,871	207,009	3.2	1,752	304,623
Oregon	1,526,724	867,977	1,592,770	1,457,414	98,304	31.2	614,701	66,635	529,562	10.1	518	150,263	1.1	2,157	89,849
Pennsylvania	4,854,988	2,397,703	4,351,774	4,016,398	173,720	60.9	1,972,561	766,131	1,083,439	21.6		509,211	2.9	72,459	631,333
Rhode Island	579,625	285,760	519,889	518,991		7.4	141,760		141,760	1.5				60,634	144,000
South Carolina	1,364,791	488,000	1,059,855	1,057,656		33.8	342,849	241,028	101,821	12.7	66,107	173,892	4.7		212,287
South Dakota	1,502,870	761,911	1,075,741	1,074,535	808	35.9	273,640	125,314	148,326	8.9	82,190	47,015	6.7	220,830	565,762
Tennessee	2,123,155	1,121,790	1,799,440	1,698,233	82,163	25.1	770,370	413,851	356,519	7.2	11,071	380,060	4.1		303,047
Texas	6,642,863	1,795,000	5,197,710	5,004,861	71,446	119.8	2,051,576	1,344,149	531,064	28.8	52,836	499,112	11.6	241,017	693,378
Utah	778,826	533,173	777,754	649,146	65,566	20.2	407,329	129,131	255,800	7.4		136,000	4.5	550	75,806
Vermont	500,509	240,611	454,392	390,966		11.9	262,696	97,248	142,046	4.8		70,326	1.9	12,296	28,239
Virginia	1,948,780	956,021	1,474,921	1,284,889	155,231	27.9	1,225,477	559,193	411,337	9.7	93,321	252,387	8.6	11,377	137,066
Washington	1,977,260	776,603	2,112,269	1,922,046	168,152	37.2	536,852	48,798	488,054	9.4		98,273	.9	6,415	22,125
West Virginia	1,342,270	570,085	1,017,690	967,807	13,293	16.5	374,171	344,863	29,308	5.4	29,600	137,058	4.0		390,427
Wisconsin	2,596,143	1,379,513	2,554,532	2,406,862	78,912	53.6	639,474	113,025	526,449	10.9		734,402	10.0	76,255	39,750
Wyoming	1,125,332	29,416	988,667	982,691	2,784	22.5	155,723	141,009	14,132	3.0				1,632	12,500
District of Columbia	946,445	181,051	877,332	696,281	181,051	6.5	250,164	250,164		.2					
Hawaii															
TOTALS	115,668,402	48,401,616	97,920,006	90,563,791	3,414,764	1,801.8	45,234,959	21,284,815	21,184,592	531.6	1,699,367	9,178,029	185.2	2,120,429	14,624,231

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF MAY 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 1,268,086	$ 1,197,828	$ 68,712	96.3	$ 1,352,044	$ 781,826	$ 570,218	87.6		$ 157,593	16.7	$ 52,799	$ 268,437
Arizona	525,423	998,032	684,085	516,393	139,878	56.8	695,428	9,030	603,790	58.8		138,677	13.2		115,687
Arkansas	1,449,634	857,024	1,229,021	1,222,992		149.0	499,805	152,568	345,790	60.5		322,316	47.2	74,073	188,918
California	3,480,440	1,999,203	3,590,636	2,984,134		164.3	1,652,915	494,605	1,021,274	53.4		518,401	15.8	1,700	459,528
Colorado	1,718,632	871,502	2,097,119	1,605,435	203,213	193.5	964,260	110,000	579,563	118.4	$ 3,197	88,726	1.2		
Connecticut	659,120	420,868	173,170	160,281	12,889	3.5	727,514	498,839	222,880	16.0					185,099
Delaware	481,113	230,849	351,392	218,550	126,792	39.9	349,959	262,563	81,793	26.5		18,000	5.0		4,264
Florida	1,302,816	1,043,543	1,576,683	1,281,312	282,574	85.5	542,598		542,598	32.0		209,434	12.2	21,504	8,937
Georgia	2,320,973	1,278,373	1,477,337	1,458,407		114.1	949,375	666,924	282,451	66.3	125,944	241,247	20.3	69,699	754,676
Idaho	1,121,562	824,450	1,325,270	1,097,735	56,671	156.1	593,003		566,655	67.6				23,827	201,124
Illinois	5,780,033	4,282,273	2,554,437	2,519,751		146.7	6,076,129	3,244,268	2,831,861	310.1	9,848	1,131,282	42.4	6,166	319,130
Indiana	731,872	135,970	408,547	385,193		44.1	373,819	310,433	63,386	49.3		46,391	6.4	36,245	26,192
Iowa	2,413,358	1,590,000	2,398,676	2,061,124	272,800	369.6	1,681,499	351,527	1,150,575	268.3		166,500	62.3	707	125
Kansas	2,522,401	1,330,595	2,223,827	2,085,242	135,727	226.5	1,567,974	381,253	1,186,721	86.4	43,499	8,147	1.6	12,407	
Kentucky	1,837,926	1,557,503	1,926,248	1,715,113	102,480	221.3	1,375,238	107,202	1,223,516	164.8		170,563	23.3	15,611	60,944
Louisiana	1,426,879	838,953	1,062,129	1,010,778	44,008	49.1	584,819	260,030	324,789	26.6	127,387	441,009	22.9	28,684	29,146
Maine	842,479	445,012	1,095,891	842,404	169,334	87.2	282,154		244,708	19.1		8,259	.5	76	22,711
Maryland	891,132	1,067,934	832,377	781,556	8,290	57.5	510,846	99,746	411,100	26.3		176,376	2.6	9,830	472,168
Massachusetts	488,185	870,000	477,470	469,741		15.2						576,837	15.9	18,444	293,163
Michigan	3,184,057	1,613,142	3,024,656	2,849,679	16,400	205.6	1,681,177	305,527	1,360,750	74.9		203,225	19.3	28,851	32,767
Minnesota	2,376,415	1,361,813	2,579,294	2,194,840	316,167	288.5	1,162,065	155,444	887,922	106.6		111,515	6.9	26,131	46,211
Mississippi	1,744,669	354,023	1,040,267	1,040,267		111.4	653,430	636,930	16,500	59.4	24,601	110,538	17.1	42,870	226,984
Missouri	2,923,273	2,423,863	2,952,588	2,686,006	190,245	634.4	1,665,691	235,551	1,384,887	275.2		753,022	138.5	1,716	95,709
Montana	1,859,937	942,434	2,008,378	1,758,063	245,842	256.4	536,560		536,560	48.6	55,249	139,455	14.3	46,626	20,577
Nebraska	1,957,240	991,091	2,396,387	1,957,240	426,115	415.1	464,470		464,470	73.5		16,291	.3		84,214
Nevada	1,136,479	852,000	1,425,415	1,113,353	285,785	179.2	317,541		317,541	30.7				23,125	248,674
New Hampshire	477,385	261,593	571,184	448,385	77,387	28.3	149,959	29,000	116,979	8.0		67,227	1.7		
New Jersey	55,099	460,000	56,528	55,099		.5						111,963	1.7		348,037
New Mexico	1,272,129	735,425	1,328,048	1,235,198	92,850	229.4	590,218	36,931	553,287	67.4		43,346	1.9		45,942
New York	3,608,768	3,822,700	3,469,145	3,035,560	80,589	86.8	4,713,570	515,500	3,438,850	281.5		92,900	8.2	57,708	210,361
North Carolina	2,380,573	1,700,340	2,375,288	2,124,767	246,495	268.2	1,352,592	223,812	1,128,780	137.2		143,100	12.8	31,994	181,965
North Dakota	1,451,112	734,742	985,272	958,863	25,777	301.5	365,418	303,127	62,291	101.9	128,054	196,749	98.7	61,069	449,925
Ohio	3,871,148	1,966,253	3,988,208	3,704,896	25,000	302.0	1,434,476	82,310	1,303,803	99.5		159,500	7.3	83,942	477,950
Oklahoma	2,304,199	1,171,295	2,040,664	1,913,305		255.7	1,367,750	385,117	818,313	62.3		181,547	15.7	5,777	171,436
Oregon	1,526,724	777,096	1,818,833	1,479,636	161,282	128.4	701,295	19,526	610,028	42.9		5,786	3.1	27,563	
Pennsylvania	7,344,822	2,639,003	6,507,456	6,221,554	129,575	545.6	3,563,760	1,123,268	2,334,046	209.2		37,780	3.1		137,603
Rhode Island	439,716	254,040	449,748	439,716		33.2	212,562		212,562	6.7		36,815	1.4		4,662
South Carolina	1,364,791	1,342,000	1,061,650	1,061,087		115.5	1,299,438	239,531	1,022,286	149.0	49,827	274,346	33.0	14,346	45,367
South Dakota	1,502,870	761,911	1,235,315	1,184,346	48,151	358.6	533,865	318,524	215,341	152.1		346,408	88.9		152,011
Tennessee	2,123,155	1,075,748	1,589,971	1,533,502		123.7	931,497	507,781	423,716	45.2	4,503	330,139	21.9	77,369	321,893
Texas	6,012,518	3,638,000	6,583,402	5,959,615	167,508	780.2	2,344,226	16,517	2,327,689	211.3	18,000	1,055,739	55.6	18,386	87,064
Utah	1,048,677	533,173	1,312,327	954,655	192,800	195.4	479,682	94,022	314,373	71.1		25,000	2.9		1,000
Vermont	438,880	241,354	520,636	437,125	28,424	37.4	226,279		212,028	15.8				1,755	903
Virginia	1,736,770	893,188	1,655,484	1,569,587	21,490	211.7	628,576	97,473	530,017	60.9	69,710	199,869	19.0		141,812
Washington	1,080,673	776,603	1,115,489	1,080,673	7,054	67.7	695,872		688,372	48.8					81,177
West Virginia	1,118,559	570,083	745,431	701,270		41.9	664,891	412,095	252,796	25.1		98,140	4.4	5,193	219,148
Wisconsin	2,431,220	1,743,354	2,347,060	2,158,518	48,583	170.4	1,509,542	258,460	1,048,936	55.7		485,414	5.8	14,242	160,421
Wyoming	1,125,332	571,928	1,139,547	1,047,459	74,683	153.5	313,414	27,126	286,285	40.4	50,747	167,583	78.1		43,377
District of Columbia	972,024	792,791	1,138,516	972,024	166,491	10.2	337,625		337,625	2.7					288,674
Hawaii	177,718	351,000	178,209	177,718		4.9									351,000
TOTALS	93,073,362	58,059,030	86,392,797	77,667,975	4,698,061	8,817.5	51,676,820	13,754,386	35,460,701	4,101.6	710,566	9,813,155	971.1	940,435	8,087,113

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF MAY 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 8,984,389	$ 6,128,064	$ 185,864	461.1	$ 4,653,237	$ 2,094,743	$ 2,013,801	258.1	$ 65,340	$ 582,874	32.7	$ 81,986	$ 1,477,303
Arizona	5,211,960	2,641,935	6,158,052	4,865,076	588,146	405.9	1,839,739	128,309	1,520,185	119.2	129,322	236,400	13.6	89,253	297,204
Arkansas	6,748,335	3,428,049	6,174,268	5,323,174	220,708	349.6	3,040,853	1,059,819	1,663,611	156.7	259,995	769,426	81.4	105,346	774,305
California	15,607,354	7,932,206	17,727,947	13,642,874	396,450	512.2	8,150,817	1,946,511	4,608,451	194.9		1,662,718	43.9	17,969	1,264,587
Colorado	6,874,530	3,486,006	8,196,248	6,603,102	1,101,703	441.1	2,859,565	220,498	2,257,268	197.8	3,197	88,726	1.2	47,733	38,309
Connecticut	2,865,740	1,454,868	1,810,574	1,757,967	22,337	28.3	2,316,482	1,107,773	940,346	40.6		143,909	1.7		348,276
Delaware	1,819,088	923,395	1,918,112	1,547,303	349,337	89.2	662,464	267,536	376,470	33.8	4,082	50,460	6.3	167	147,128
Florida	5,231,834	2,661,343	6,487,177	4,926,030	446,785	224.9	1,552,201	191,660	1,310,385	66.2	19,986	426,889	17.4	94,159	477,284
Georgia	10,091,185	5,113,491	7,251,066	6,707,532	255,697	466.1	4,774,388	2,826,992	1,857,384	221.3	132,338	846,888	36.1	424,323	2,153,521
Idaho	4,486,249	2,277,486	4,553,838	4,176,117	95,230	358.5	1,636,512	237,867	1,358,246	118.5				72,265	824,010
Illinois	17,570,770	8,921,401	11,174,109	10,783,608	19,269	251.7	12,151,738	6,700,514	5,451,224	384.8	60,108	2,372,047	51.0	26,540	1,078,861
Indiana	10,037,843	5,088,963	7,060,466	6,815,442		219.1	5,351,053	2,880,539	2,432,835	213.7	226,065	2,227,931	69.6	115,796	428,197
Iowa	10,055,660	5,118,361	9,231,845	8,590,422	409,705	713.1	5,740,381	1,463,492	3,763,759	435.6	1,000	468,995	72.9	746	475,902
Kansas	10,089,604	5,117,675	10,469,748	9,403,352	770,239	876.2	4,852,163	573,397	4,195,669	254.5	91,857	151,767	6.0	20,997	
Kentucky	7,517,359	3,818,311	6,937,492	6,388,919	142,528	496.8	3,311,233	1,017,175	2,163,484	257.8	30,000	932,623	49.0	81,265	579,676
Louisiana	5,828,591	2,963,932	4,486,025	4,010,450	97,655	144.7	3,412,522	1,525,368	1,691,849	71.9	242,779	660,592	28.0	49,994	513,836
Maine	3,369,917	1,711,586	3,282,260	2,982,103	179,831	147.9	1,225,192	295,565	892,181	33.1	83,948	519,354	12.3	8,301	120,220
Maryland	3,564,527	1,810,058	2,084,612	1,957,185	78,650	77.2	2,534,975	1,159,435	562,019	48.5		176,376	2.6	447,907	993,013
Massachusetts	6,597,100	3,350,474	4,046,888	3,604,640		66.1	4,069,549	2,929,059	1,063,693	18.3		777,439	24.3	63,402	1,509,342
Michigan	12,736,227	6,452,568	11,288,275	10,621,138	202,200	469.5	7,019,177	2,002,777	4,948,800	235.7	14,950	863,450	50.0	97,362	438,118
Minnesota	10,656,569	5,425,551	11,624,285	9,492,911	1,857,669	1,303.4	3,283,443	929,248	2,122,412	245.1	75,328	451,392	55.2	159,082	994,078
Mississippi	6,978,675	3,540,227	6,766,622	4,363,876	343,747	387.8	4,513,214	2,237,029	1,513,694	244.4	225,241	888,670	71.4	152,529	794.116
Missouri	12,180,306	6,173,740	10,633,326	9,737,803	209,036	875.8	5,941,746	2,225,109	3,397,156	379.5		1,094,178	153.2	217,395	1,473,370
Montana	7,439,748	3,769,734	9,137,276	7,242,898	1,381,760	798.6	2,124,140	38,846	1,958,664	180.8	108,087	353,840	19.6	49,918	75,470
Nebraska	7,828,961	3,964,364	9,791,560	7,769,964	840,880	824.4	3,152,171	25,639	2,771,497	183.6		59,239	5.5	33,357	292,748
Nevada	4,545,917	2,302,356	5,077,720	4,255,400	718,806	491.3	1,251,542	202,644	1,048,230	151.6	17,734	14,755	2.6	70,138	520,565
New Hampshire	1,909,839	969,462	1,931,852	1,729,551	127,238	55.0	824,654	180,288	618,438	23.5		118,162	2.0		105,624
New Jersey	6,346,039	3,220,879	4,309,291	4,159,382		53.5	3,414,120	2,046,600	968,276	25.3		493,850	4.0	140,056	1,758,753
New Mexico	5,792,935	2,941,700	6,476,449	5,463,037	869,483	612.9	1,746,188	245,957	1,429,337	135.1	4,129	43,346	1.9	79,812	599,534
New York	22,330,101	11,327,921	21,067,027	18,077,786	561,319	357.2	18,221,754	3,852,687	9,802,020	458.7	109,000	197,400	8.2	290,629	767,182
North Carolina	9,522,293	4,840,941	9,569,731	7,756,698	874,331	941.1	3,520,537	1,221,886	2,071,274	317.8	231,123	846,696	40.6	312,586	1,048,640
North Dakota	5,804,448	2,938,967	5,215,765	4,594,602	166,205	1,409.6	1,357,675	591,154	597,351	355.5	372,037	652,685	254.1	246,656	1,522,726
Ohio	15,484,592	7,865,012	15,944,007	14,760,489	60,545	551.2	6,810,036	440,530	5,852,693	193.0	196,150	427,720	12.4	87,423	1,524,054
Oklahoma	9,216,798	4,685,180	8,665,053	7,880,388	452,321	610.2	4,371,439	1,281,849	2,709,569	158.5	45,902	909,595	41.8	8,659	613,784
Oregon	6,106,896	3,097,814	7,011,018	5,901,350	539,533	353.5	2,485,199	166,751	2,128,582	102.5	518	270,909	10.0	38,278	158,791
Pennsylvania	18,891,004	9,590,788	17,273,851	15,954,343	734,960	739.2	10,554,882	2,805,117	7,300,454	317.9	2,126	589,815	7.1	129,418	965,559
Rhode Island	1,998,708	1,014,572	1,937,642	1,858,334		61.1	914,914	79,740	818,895	22.5		36,815	1.4	60,634	158,862
South Carolina	5,459,165	2,770,954	4,520,114	4,379,226	73,571	353.7	2,405,978	855,142	1,513,215	227.9	174,641	476,237	40.1	50,157	707,931
South Dakota	6,011,479	3,047,643	5,115,500	4,495,052	139,683	872.3	2,140,235	1,042,564	1,083,012	418.4	195,644	985,503	189.2	278,219	839,445
Tennessee	8,492,619	4,302,991	8,216,555	7,233,092	266,842	337.8	3,156,823	1,098,178	1,962,243	99.2	25,062	1,266,412	46.2	136,286	807,494
Texas	24,244,024	12,291,253	23,811,226	22,107,957	563,618	1,943.7	10,042,235	1,749,921	7,916,317	664.3	110,726	2,049,189	108.2	275,420	1,762,129
Utah	4,194,708	2,132,691	5,104,463	3,928,652	734,891	474.1	1,524,040	·260,153	1,007,723	123.0		161,000	7.4	5,903	229,077
Vermont	1,867,573	948,007	1,955,715	1,739,753	56,887	97.2	870,531	107,918	696,936	38.1		150,550	4.1	19,902	43,634
Virginia	7,416,757	3,765,387	7,005,733	6,222,366	440,219	400.5	3,488,558	882,397	2,230,131	138.5	274,521	739,018	53.5	37,473	356,019
Washington	6,115,867	3,106,412	6,108,162	5,623,231	374,000	205.9	2,908,994	450,809	2,330,105	86.7		161,939	1.5	41,826	240,369
West Virginia	4,474,234	2,280,335	3,696,691	3,516,406	74,185	129.6	1,755,669	868,628	870,149	55.9	73,971	356,037	13.0	15,229	979,964
Wisconsin	9,724,881	4,941,837	9,356,561	8,674,021	235,580	435.6	3,869,373	943,244	2,716,774	141.9	182	1,745,614	36.1	107,434	243,869
Wyoming	4,501,327	2,287,712	4,721,255	4,094,704	442,577	684.0	1,795,609	350,526	1,418,331	248.0	50,747	323,123	98.5	5,350	103,681
District of Columbia	1,918,469	973,842	2,015,847	1,668,305	347,542	16.7	587,789	250,164	337,625	2.8					288,674
Hawaii	1,871,062	949,778	1,020,210	704,442		24.2	1,334,240	1,155,109		20.3				11,511	949,778
TOTALS	394,000,000	200,000,000	374,403,898	326,220,517	19,049,762	23,200.3	191,521,969	59,214,856	116,262,763	9,121.3	3,657,836	29,822,463	1,888.8	4,906,791	34,865,012