# Earth-Resistivity Tests Applied as a Rapid, Nondestructive Procedure for Determining Thickness of Concrete Pavements

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•EARTH-RESISTIVITY tests have long been employed as a rapid procedure for making subsurface explorations dealing with such highway construction problems as slope design, foundation conditions, landslide investigations, and location of construction materials. Equipment for making such tests has been built or purchased by 39 states and Puerto Rico. In a continuing search for rapid, nondestructive test procedures for use in conjunction with or in lieu of currently used destructive tests, the U. S. Bureau of Public Roads has adapted the electrical resistivity test to determine the thickness of concrete pavements.

This test involves measuring the resistance to the passage of an electric current through the selected medium. The test is made by using four electrodes equally spaced in a line on the surface of the material being tested (see Appendix). The nature of the test is such that the effective depth (penetration of the applied current) can be varied and controlled by the spacing of the four electrodes as the test progresses; i. e., the effective depth is equal to the electrode spacing for a particular setting of the electrodes. Thus, when testing a concrete pavement the electrode system may be spaced at a 1- or 2-in. spacing for the initial readings of current and potential change, and the system expanded in 1-in. increments for successive readings extending to a total depth of 3 to 6 in. below the bottom of the pavement. Four small plastic tubes, plugged with stiff clay and filled with a saturated solution of copper sulfate into which a copper wire is inserted, are used in the test (Appendix, Fig. A-3). The clay, with the help of a slight wetting of the concrete surface, provides a suitable contact for the electrical circuits with the pavement surface.

A concrete pavement has a resistivity characteristic that usually differs from that of the underlying soil or base layers. When plotting resistivity against electrode spacing or depth, a change in resistivity is normally encountered in the base layer that will produce a recognizable trend in the curve towards a higher or lower resistivity, signifying the presence of the underlying material. Using the Moore Cumulative Curve Method of depth determination (briefly described in the Appendix), it is possible to draw straight-line portions of the cumulative curve to intersect in the vicinity of the trend appearing in the field curve (dashed-line curve in several figures), the depth at which the intersection is obtained being equated to the thickness of the layer under test.

The results of some 150 tests, made on both unreinforced and reinforced concrete slabs and on bridge decks, have been good. A linear regression analysis of resistivity measurements and direct pavement thickness measurements made at 68 locations gave the following results: (a) an average thickness ($\bar{Y}$) of 9. 55 in., (b) a standard error of estimate ($S_E$) of 0. 226 in., and (c) a coefficient of variation of 2. 36 percent. However, it should be emphasized that some experience in the use of the test and the method of analyzing the test data may be required for the best results. Much more testing is needed to determine the effectiveness of the proposed test procedure under all field

Paper sponsored by Committee on Mechanical Properties of Concrete.

conditions, varying concrete mix, air entrainment and water-cement ratio of the concrete, and base-course design.

Steel reinforcing produces recognizable changes that do not interfere with thickness measurements and, in fact, offers a good possibility that the effects could be utilized to measure the depth of the steel. More work is needed, however, to determine whether a dependable depth determination is possible without some prior knowledge of the position of the steel beneath a test center.

## TESTS ON CONCRETE ROADWAY PAVEMENT

Figure 1 shows the data plotted for a test made on a 9-in. plain (nonreinforced) concrete pavement recently placed in the repair of a section of the George Washington Memorial Parkway in Northern Virginia. The gradual but definite uptrend appearing in the dashed-line curve at a depth of 8.0 in. is the basis for choosing the intersection of the solid straight lines at 8.85 in. in the cumulative curve as an indication of the thickness of the slab. The thickness established by level rod readings made on the top of the compacted sand and gravel base and on the finished concrete surface is shown along the base of the graph. The relatively close check between the results of the resistivity test and the directly measured thickness is not uncommon. For 31 locations on this project, the variation of the resistivity thickness determinations from the linear regression equation ranged from +0.35 to -0.57 in., with an average deviation of 0.141 in. (1.52 percent). When it is considered that a much larger sample is involved to some degree in the resistivity test (an area 45 in. by 18 in. for a 9-in. slab) in contrast to the 4-sq in. area of the level rod base, any small percentage difference becomes even less significant.

The foregoing results and other tests made on plain concrete slabs appear to confirm the test procedure for use under such conditions. Other variables, such as the presence of steel reinforcing and the age of the structure, remain to be evaluated. Figure 2 shows the results of a test made on a slab, nominally of 9-in. thickness, with reinforcing steel in the upper third of the slab. This test was one of 34 made on Interstate 66 in Rosslyn, Virginia, just prior to its being opened for traffic. The sharp downtrend in the early part of the dashed-line curve of Figure 2 was produced by the effect of the steel reinforcing present in the upper third of the pavement. As noted earlier, this effect on the measured resistivity may have significance in obtaining information concerning the position of the steel. However, it should be emphasized that the primary purpose of the several tests under discussion was to obtain overall thickness measurements of the concrete slabs involved. Mention of the possible location of the position of the reinforcing steel in subsequent paragraphs is made in a discussion of the extra downtrends appearing in the curves and to suggest, perhaps, that further consideration should be given to this possible use of the test. Further discussion of this possibility is made in a later section.

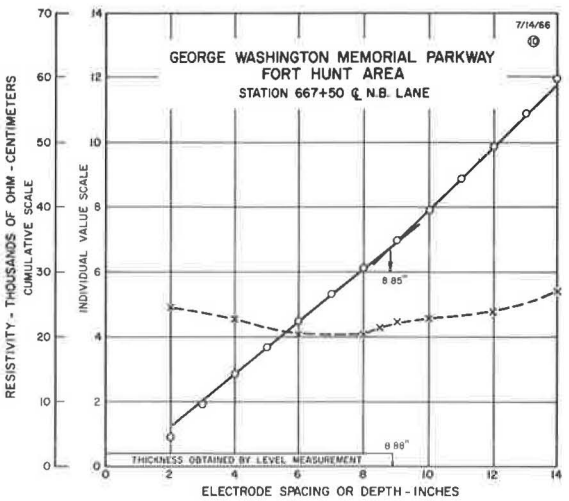


Figure 1. Earth-resistivity test over plain concrete slab to obtain thickness—sand and gravel base.

The presence of the steel makes it possible for abnormally high current densities, not controlled by the resistance of the concrete mass, to be recorded, which results in the rapid drop in resistivity shown in the curve of Figure 2. This effect continues as the test progresses through the pavement and becomes more pronounced as the effective depth reaches and passes the contact between the pavement and the underlying base material (cement-treated sand and gravel). The

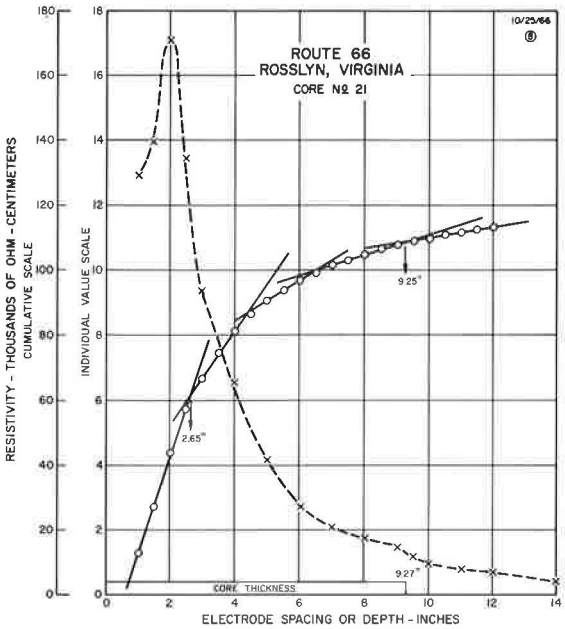


Figure 2. Earth-resistivity test over reinforced concrete roadway slab to obtain thickness—cement-treated base.

test was not carried to a sufficient depth to permit an attempt to determine the thickness of the base course. The thickness obtained by a measured core is shown at the base of the graph. The good agreement between measured thickness (9. 27 in.) and resistivity results (9. 25 in.) suggests that a very uniform bottom condition exists throughout the 5- to 6-sq-ft area of the slab likely to influence the test to some degree. The two intersections obtained in the cumulative curve (solid-line curve) at 4. 35 in. and 6. 5 in. were discounted as not being significant in the analysis, in the absence of additional recognizable trends in the dashed-line curve. Similar extraneous intersections also were obtained in the cumulative curves of Figures 4 and 5. The higher initial resistivity values of Figure 2, when compared to those involving the first 8 in. in the preceding graph for the test on plain concrete, which averaged 4, 500 ohm-cms, are likely a result of air entrainment, effect of curing compound, and differences in the composition of the concrete used on the two construction projects.

Although the time required to make the 16 separate determinations of resistivity used to plot the dashed-line curve in Figure 2 was 15 to 20 minutes, further simplification of apparatus and field techniques could reduce the required time to only a 5- to 10-minute period. For example, if there was no interest in attempting to determine the depth of the reinforcing steel, resistivity readings beginning with an electrode spacing of 7 in. (corresponding to an initial depth of 7 in.) and continuing only to a 12-in. depth would produce sufficient data to permit a satisfactory thickness determination for a 9-in. concrete slab. Also, assuming no interest in a measurement of natural potentials, sometimes an important adjunct to resistivity measurements, alternating current apparatus could be devised to permit a direct reading of resistivity that could speed up an analysis of the data obtained.

Figure 3 shows resistivity data for a test made on a 5-in.-thick slab with steel mesh reinforcing at the midpoint. This slab, recently placed on the

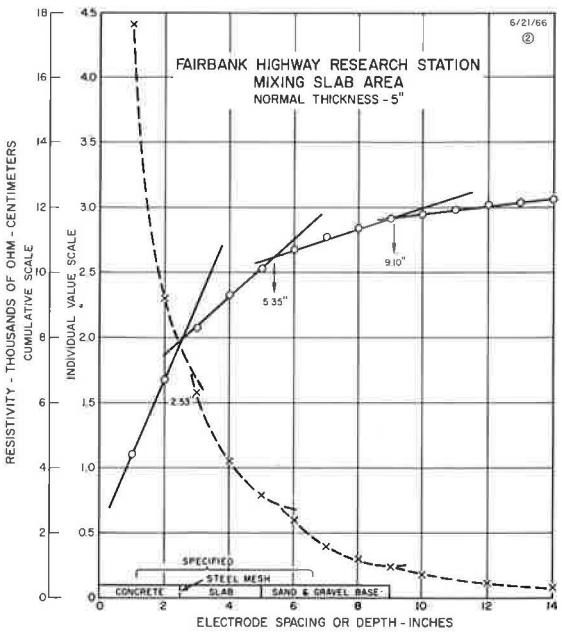


Figure 3. Earth-resistivity test over reinforced concrete slab—5-in. thickness on sand and gravel base.

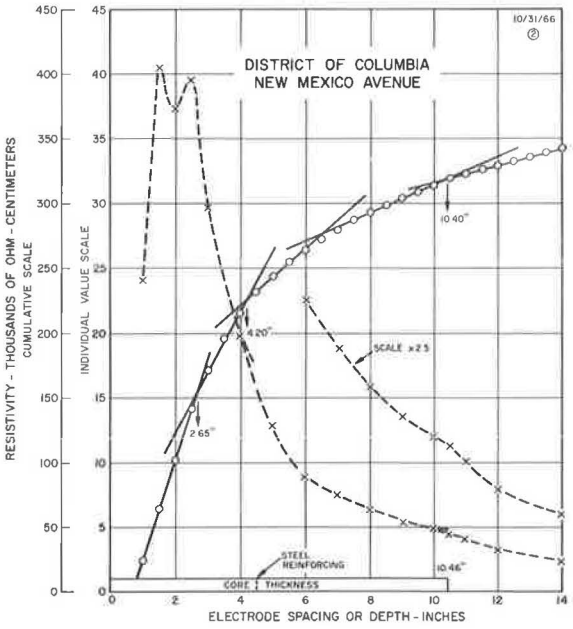


Figure 4. Earth-resistivity test over reinforced concrete roadway slab—10-in. thickness.

grounds of the Fairbank Highway Research Station, provided a 30- by 40-ft working surface for mixing large masses of soil for laboratory use; thickness control could have been rather casual. The changes indicated at depths of 2.53, 5.35, and 9.10 in. appear to be associated with the depth of the steel reinforcing, the bottom of the concrete slab, and the bottom of the 4-in. layer of granular base beneath the slab, respectively. The results of seven tests made on this slab gave average depth values of 2.65, 5.16, and 9.21 in. for the three changes shown in Figure 3. No direct measurements of the slab thickness, position of the reinforcing steel, and the base-course thickness have been made at this location.

Figure 4 shows data for tests made on a reinforced concrete pavement subjected to 3 or 4 years of traffic on New Mexico Avenue in Washington, D. C. The changes shown at depths of 4.20 and 10.40 in. have apparently located the position of the steel and the bottom of the slab. The length of the core obtained at this location was 10.46 in. The average thickness for four tests made on the project was 0.1875 in. lower than that found by coring. The change showing at a depth of 2.65 in. in Figure 4 is likely associated with near-surface changes in the concrete.

Tests made on both plain and reinforced concrete roadway slabs in service for 17 years produced resistivity-thickness curves of substantially the same character as those shown in the figures. Apparently, corrosion of the reinforcing steel, if present, does not cause a significant change in the recorded effect of the steel on the measured values of the resistivity.

## TESTS ON CONCRETE BRIDGE SLABS

It would seem that a much closer control of steel positioning and slab thickness is possible when placing concrete bridge slabs and, consequently, there would be less need for a nondestructive thickness test for such structures. The resistivity test should be considered as a possible rapid, nondestructive test procedure, however, if coring is done or if there is a definite need to locate the steel reinforcing after construction. Figure 5 shows

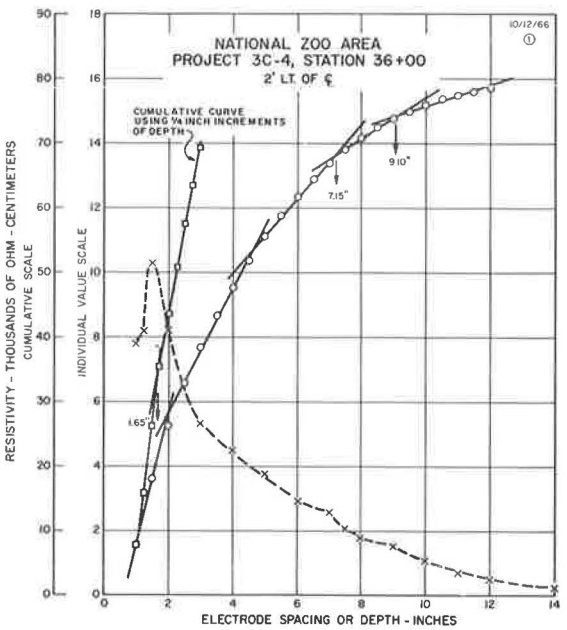


Figure 5. Earth-resistivity test over top slab of box girder bridge structure—9-in. section.

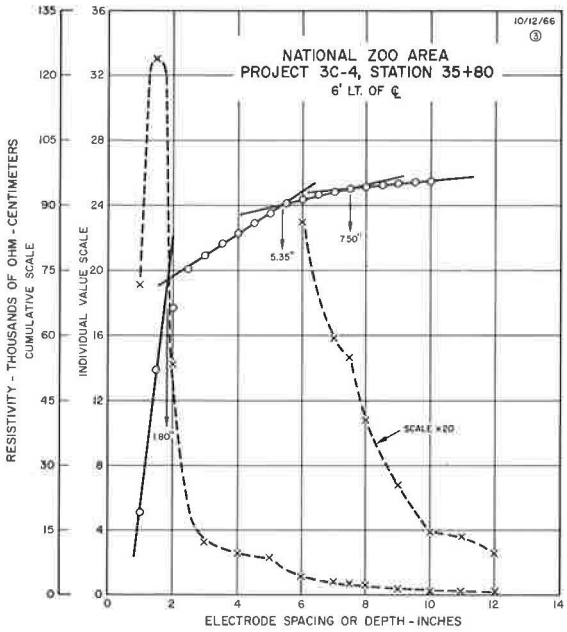


Figure 6. Earth-resistivity test over top slab of box girder bridge structure—7-in. section.

data obtained on the top deck of a concrete box girder bridge in the District of Columbia. The changes indicated at depths of 1.65 and 7.15 in. are associated with the steel reinforcing cage. The data for the first 3 in. of depth in the curve of Figure 5 were replotted in a cumulative relation using a ¼-in. increment of depth to obtain the change shown at a depth of 1.65 in. The final change at 9.10 in. represents the bottom of the slab. Similar results were obtained elsewhere on the bridge where a 9-in. thickness was specified. The average depths obtained for the seven tests made were 1.80, 7.25, and 9.14 in.

Figure 6 shows the results of a test made over a section of the bridge deck having a 7-in. specified thickness. The probable position of the steel in this instance was indicated at depths of 1.80 and 5.35 in., the slab thickness being 7.50 in. The results from 10 tests made over the 7-in.-thick areas gave average values for these three depths of 1.86, 5.21, and 7.04 in. respectively.

## LOCATION OF REINFORCING STEEL

An extra dividend of resistivity tests to obtain slab thickness may be the location of the reinforcing steel in reinforced concrete pavements. If this is a current problem in post-construction evaluation of reinforced concrete pavements, the resistivity test should certainly be given a thorough trial for such use. In Figure 2, the change at a depth of 2.65 in. was produced by steel mesh found at a depth of 3.0 in. in the core. In Figure 3, the change found at a depth of 2.53 in. showed good agreement with the design depth of 2.50 in. shown on the graph. In Figure 4, the change at a depth of 4.2 in. compares fairly well with the depth of 4.5 in. found for the steel in the core removed from the pavement. No direct check for steel positioning was made for the test locations involved in Figures 5 and 6. The specifications indicated a 1½-in. cover for the steel near to the surface of the bridge slab and a 1.0-in. cover at the bottom. The average cover indicated by the 17 tests made on the bridge was 1.83 in. at the top and 1.86 in. at the bottom.

Some error could be introduced into the measurements made to locate the steel, however, due to the size and location of the steel bars with respect to the test center. Random positioning of the center of the electrode system between two bars rather than directly above a bar could possibly affect the depth indicated. Also, it is not known whether the effect produced on the resistivity measurements corresponds to the top of the steel or its center. Obviously, much trial testing over known steel positioning will be necessary before the effect of such possible sources of error can be fully evaluated.

## CONCLUSION

Although the results obtained thus far in attempting to measure the thickness of concrete by use of the earth-resistivity test suggest a very useful application of the test, there is need for further trial tests. These, preferably, should be made by personnel of several state highway departments scattered throughout the country, to thoroughly evaluate the test procedure for conditions existing in differing geologic areas and

to involve a wide variety of concrete mixes and base layer construction. Because many states already have equiment useful for such research, new HPR research programs might readily be actuated. Such testing should not overlook the possible use of the measurements to locate the steel in reinforced concrete slabs.

## *Appendix*

The earth-resistivity test involves the introduction of a direct or alternative electric current into the material being tested and the measurement of its resistance to passage of the current. Four electrodes are used and are spaced equal distances apart and on a straight line (Fig. A-1). The current passing through the material between electrodes $C_1$ and $C_2$ is measured, and the potential drop between electrodes $P_1$ and $P_2$ is recorded. The resistivity for a 1-cc volume is computed by using the formula $P = 2\pi A E/I$, in which A is the electrode spacing in centimeters, E the potential drop in volts, and I the current in amperes flowing between $C_1$ and $C_2$. The assumption is made that equipotential hemispheres or bowls with a radius A are established around each current electrode ($C_1$ and $C_2$). Every point on the surface of a hemisphere has the same potential. By placing the potential electrodes $P_1$ and $P_2$ at points on the surface where these hemispheres intersect the ground surface, it is possible to measure a potential drop that applies equally well at a depth A below the surface. As the electrode system is expanded to involve greater depth, the bottom of the hemispherical zones may involve a layer of differing electrical resistivity, which produces a trend towards lower or higher resistivity and gives an indication of depth to the layer producing the resistivity change. The resistivity values are plotted against electrode spacing or depth as shown by the dashed-line curve of Figure A-2. The solid-line curve of Figure A-2 is a cumulative plotting of the data for the dashed-line curve in which the first point is the same value as the first point of the dashed-line curve plotted to a condensed scale, the second point is the sum of the resistivities for the first and second points, the third point is the sum of the resistivities for the first three points, etc. Using a constant increment of depth throughout, i. e., 3 ft, the solid-line curve constitutes a graphical integration of the dashed-line curve. Straight lines drawn through the plotted points in the vicinity of a trend in the dashed-line curve intersect to give the depth to the subsurface layer producing the trend.

Figure A-3 shows a typical miniature resistivity test in progress. The small plastic tubes are plugged with stiff clay and filled with a solution of copper sulfate in which copper wires are immersed. The clay permits a very slow movement of the copper sulfate solution to the concrete surface and, along with a slight wetting of the concrete surface, provides for good electrical contact. These electrodes are spaced at a 1- or 2-in. initial setting, when testing thing layered structures such as concrete pavements, and are expanded with 1- or 2-in. increments to carry the test to a depth some 3 to 6 in. below the bottom of the layer being investigated. Generally, with respect to concrete pavements, there is a measurable difference in resistivity between concrete and the materials normally used in the base layers.

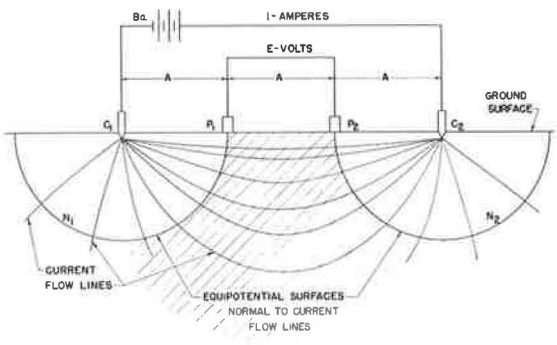


Figure A-1. Equipotential bowls assumed beneath current electrodes when making earth-resistivity tests.

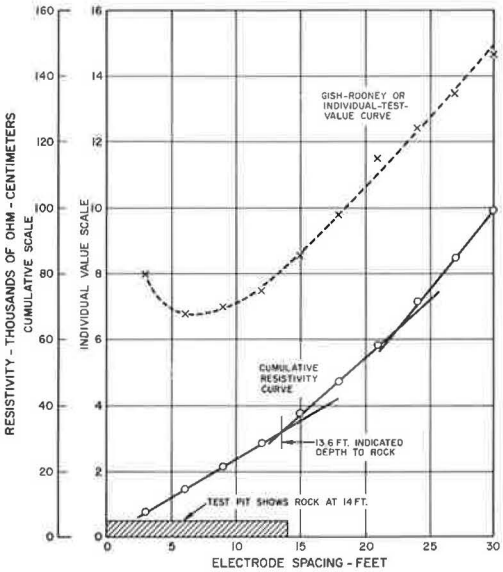


Figure A-2. Typical resistivity data and method of analysis using the cumulative resistivity curve.

Figure A-3. Typical miniature resistivity test in progress on concrete pavement.