In the last column, we discussed the measurement of soil resistivity, which is a test of the electrical properties of soil itself, independent of any grounding electrode or other human installation. The basic formula for calculating the measurement is called the “Wenner Formula”, and is given as:

\[ \rho = 2\pi AR \]

where \( \rho \) is average soil resistivity, \( A \) is the spacing of the test probes, and \( R \) is the test instrument’s reading. The Wenner formula is actually a simplification of the general formula, and has built into it the qualification that the test probes be inserted into the soil in a ratio of \( \frac{1}{20} \) their horizontal spacing. The general formula is:

\[ \rho = \frac{4\pi AR}{1 + \frac{2A}{\sqrt{A^2 + 4B^2}} - \frac{2A}{\sqrt{4A^2 + 4B^2}}} \]

where \( A \) equals probe spacing as before, and \( B \) equals probe depth. However, it has been determined that if \( A > 20B \), most of the terms drop out, and the formula simplifies to the familiar Wenner model. For obvious reasons, the simpler option is preferable in fieldwork!

Practical experience indicates that strict adherence to the Wenner probe ratio isn’t always necessary. As has been pointed out in prior columns, much of fieldwork is a judicious compromise between real world situations and the ideal models that have been derived in laboratory research and development. The main ingredient for success is to understand the basis for the ideal model. That way, the field operator knows the essential points and how much variation might be allowable for the particular goals. In the case of the Wenner method, field research indicates that an “eyeball” approximation of the standard probe ratio yields reasonable results. After all, soil resistivity itself, considering that typical values can vary by several powers of ten, is not that precise.

However, depending on the desired accuracy of test results, the more general formula can be employed in demanding situations. These would include difficult soils that do not support probes well to begin with, such as rocky soils, where shallow probe penetration may not afford sufficient contact to meet test parameters. Similarly, since horizontal spacing between probes determines depth of measurement, surface measurements may require significant deviation from the \( \frac{1}{20} \) ratio in order to get sufficient contact. The extreme of this condition would be surface measurement on coated surfaces where probes cannot be driven at all. Modern testers of high sensitivity will still yield a reliable measurement, so, in theory, the calculation should work. However, in this instance, the “ideal model” is being pushed to its limits, so a representative loss in accuracy would have to be taken into account. The surface medium itself (concrete, tarmac, etc.) would take the place of the first few inches of topsoil, and the measurement, being an average resistivity to the designated depth, would be skewed accordingly.
A number of variations have been devised, thus freeing the operator from being locked in to a “recipe” approach to field applications. At the opposite extreme from the classic Wenner configuration is the occasion where probe depth exceeds probe spacing. In this case, the formula becomes \( \rho = 4 \pi AR \). This has not proven to give reliable results, however, because of the concentration of overlapping fields around the probes, and so is not recommended. Other probe arrangements are also possible in addition to the standard \( C_1, P_1, P_2, C_2 \) series described in the previous column. Potential probes can also be set on the outside of the current probes, as \( P_1, C_1, C_2, P_2 \). They can also be set in tandem, as \( C_1, C_2, P_1, P_2 \) or \( P_1, P_2, C_1, C_2 \), in which case the formula becomes \( \rho = 6 \pi AR \). Finally, the arrangement can be alternating probes, as \( C_1, P_1, C_2, P_2 \), or \( P_1, C_1, P_2, C_2 \), where the formula becomes \( \rho = 3 \pi AR \). In these cases, the standard 1/20 ratio is best observed. It is not clear what advantages these options afford, other than as a possible means of dealing with highly atypical situations, such as numerous obstructions.

Other methods that are extensions of the Wenner principle are used infrequently, and afford the operator additional flexibility in dealing with “real world” problems. One of these is called Lee’s method of partitioning. This method uses five probes instead of the usual four, but don’t worry – the tester still only needs four terminals. The two current probes occupy the end positions, and are separated by a spacing of 3 times \( A \) (Figure 1). As usual, \( A \) is equivalent to the depth that is to be measured. However, now three probes are positioned internally, at spacings of \( A \) from the current probes and \( \frac{1}{2} A \) from each other. Again, as usual, the 1/20 depth ratio is observed. Two tests are performed, the first with the potential terminals connected to the first two potential probes, and the second with the connections moved to the second and third. Two resistivity values are then calculated, using the formulae \( \rho = 4 \pi AR_{12} \) and \( \rho = 4 \pi AR_{23} \). If the two values disagree, it is an indication of soil nonhomogeneity. This enables the operator to make a quick determination, by merely switching terminals rather than moving probes, of whether the selected depth is multilayered. Vertical profiles can then be made by varying the spacing or a line traverse performed by moving the system.

A modified method that helps deal with obstructed or other difficult terrain is the central electrode method. In this, the \( C_1 \) current probe is placed a considerable distance from the remaining rig, and does not have to be in line either (Figure 2). The distance between the current probes should be at least ten times that between \( C_1 \) and \( P_2 \). This spacing will make the effect of \( C_2 \) negligible, thereby permitting it to be left in place and only the remaining probes moved when performing a survey. The formula:

\[
\rho = \frac{2 \pi ab}{(b-a)} R
\]

where \( a \) equals the \( C_1 P_1 \) spacing and \( b \) is the \( C_1 P_2 \) spacing, yields resistivity to a depth approximately \( \frac{3}{2} (a + b) \). Since the calculation depends only on the spacing of three of the four probes, one probe \( (C_2) \) can be left in place.

An uncased borehole can also be used to make a vertical survey of the surrounding soil. In this highly unusual configuration, \( C_1 \) is driven somewhere on the surface, and \( C_2 \) is a spherical electrode of about eight inches diameter suspended down the borehole.
Similarly, P₁ and P₂ are also spherical electrodes, about 2 inches diameter, suspended down the hole (Figure 3). The borehole is typically filled with a fluid, such as drilling mud, that makes good electrical contact with the electrodes. As with the previous method, a large distance should be maintained between the current electrodes in order to eliminate any effects of C₁. In this case, the surface distance between C₁ and the borehole where the potential probes are suspended should be at least six times the distance between the suspended C₂ and P₂. If this configuration prevails, the formula becomes:

$$\rho = 4\pi (r_1 r_2 / r_1 - r_2) R$$

where r₁ is the distance between C₂ and P₁, and r₂ is the distance between C₂ and P₂. This arrangement gives average resistivity for the layer between the potential probes and by lowering down the hole, can produce a vertical profile of soil layers. To complete the profile with the bottom layer, since it is not practical to try to drive C₂ into the bottom of the hole, the positions of C₂ and P₁ are interchanged.

These techniques yield values that the literature often refers to as apparent resistivities. They differ from the strict definition of resistivity as it applies to a pure material, such as copper or aluminum, because soil tends to be nonhomogeneous. Nevertheless, though the measurements might not always pass academic muster in terms of “pure” science, they are valuable and useful tools for practical application. We will further examine some of these applications in a future article.

References


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