Comparisons of Soil Resistivity Meters Used with Pre-Measured Cable Sets

By

AKM Sydul Haque, Ph.D., P.E., ELK Engineering Associates, Inc.

and

Earl L. Kirkpatrick, P.E., ELK Engineering Associates, Inc.

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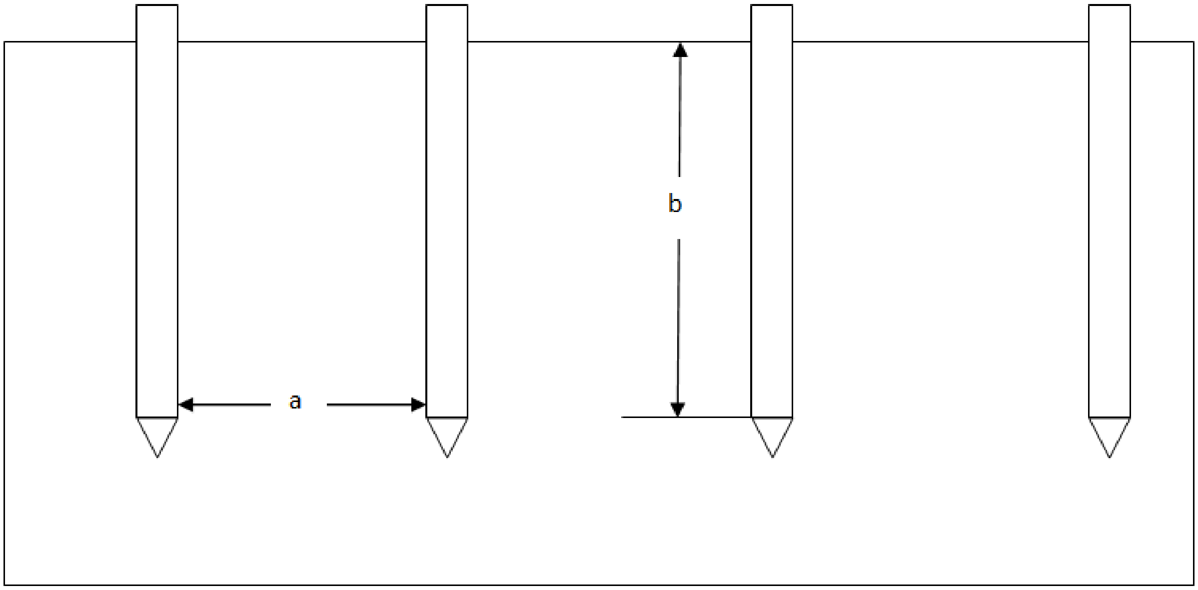
ABSTRACT

Soil resistivity is used for designing groundbeds for Cathodic Protection and for determining the necessity of Cathodic Protection. Soil resistivity is also required for designing grounding grids to protect personnel and equipment. It is also useful for estimating the depth of bedrock, the water table, or other geological features. This paper presents a detailed investigation of commercially available soil resistivity meters when using a pre-fabricated cable set. Resistance comparisons are made between using individual leads or pre-measured cable sets for measuring soil resistivity in various soil environments. A pre-measured cable set has the advantages of convenience, improved the speed of field measurements, and accuracy in pin spacing. Thus decreasing the measurement error. A disadvantage of pre-measured cable sets can be crosstalk between the wires. All of the meters evaluated for this paper generated an AC signal output and could be capable of producing crosstalk in the cable set. Comparative measurements were taken for depths of 5', 10', 15', and 20' at low to medium soil resistivity environments. High to very high resistivity soils were simulated in the laboratory using power resistors. The errors were widespread between individual meters, ranging from 0% to 73.61%. More errors were found at lower resistivity soils. Of all meters tested, two meters performed very well for a wide range of soil conditions. The maximum error for one meter was 2.778% and the other was 2.857%. Indiscriminate soil testing with a meter and cable set without verifying accuracy is a poor practice which can result in gathering useless data.

THEORY

Frank Wenner published a paper "a method of measuring earth resistivity" in a National Bureau of Standards, Scientific Paper, July 15, 1915. He suggested the following method. Place four holes in the earth approximately uniformly spaced in a straight line. The diameter of the holes is not more than 10% of the distance between them and the depth of the holes are approximately equal. An electrode is placed in each hole which makes electrical contact with the earth only near the bottom. The resistance depends on the distance between the electrodes. But it does not depend appreciably upon the size of the electrodes nor the kind of the electrical connection they make with the earth.



Here a = distance between the holes

b = depth of the holes

ρ = resistivity

R = the measured resistance

$$\rho = \frac{4\pi a R}{1 + \frac{2a}{\sqrt{a^2 + 4b^2}} - \frac{2a}{\sqrt{4a^2 + 4b^2}}} = \frac{4\pi a R}{n}$$

Where b = a, n = 1.187

b = 2a, n = 1.038

b = 4a, n= 1.003

If b>>a, ρ = 4πaR

If b<<a, ρ = 2πaR

The resistivity can be calculated if holes are not in a straight line or are not in a uniform depth or spacing. Uniform soil resistivity is considered in deriving this equation. If soil resistivity is not uniform, an accurate solution is not possible.

CROSSTALK/COUPLING

Crosstalk is a phenomenon by which a signal or circuit is unintentionally affecting another signal or circuit. Crosstalk is usually caused by undesired capacitive, inductive, or conductive coupling from one circuit, part of a circuit, or channel, to another. Some examples of crosstalk are as follows:

In telecommunication: Speech or signal tones leaks from other people's connection. Twisted pair cables are used to reduce the effect of crosstalk in analog circuits. If the connection is analog, twisted pair cabling can often be used to reduce the effects of crosstalk. Alternatively, the signals can be converted to digital form to reduce the crosstalk. In wireless communication, crosstalk is often denoted co-channel interference, and is related to adjacent-channel interference. In stereo audio reproduction crosstalk can refer to signal leaking across from one program channel to another.

Capacitive coupling is the transfer of energy or signal by means of capacitance between two nodes. It is often unintended, such as the capacitance between two wires or PCB traces that are next to each other. To reduce coupling, wires are often separated as much as possible, or ground lines or ground planes are run in between signals.

Two conductors are referred to as mutual-inductively coupled or magnetically coupled when they are configured such that change in current flow through one wire induces a voltage across the ends of the other wire through electromagnetic induction. The amount of inductive coupling between two conductors is measured by their mutual inductance.

Unintentional coupling is called cross-talk, and is a form of electromagnetic interference. Inductive coupling favors low frequency energy sources. High frequency energy sources generally use capacitive coupling.

Pre-measured cable sets have the following advantages:

- Convenient to use.
- It improves the speed of field measurements.
- Accurate pin spacing. Thus decrease the measurement error.

A serious disadvantage of using a pre-measured cable set can be crosstalk between the wires, depending on the instrumentation used for the measurement.

DC resistivity techniques measures the soil resistivity by driving a direct current signal into the ground and measuring the resulting potentials created into the soil.

INSTRUMENTS

All DC instruments has relatively less measurement error compare to AC instrument. Inductive and capacitive reactance is not a factor for DC instruments. The only sources of errors are instrument's sensitivity and operator's reading error.

Older Analog instrumentation, such as the Associated Research Vibroground, measured the true resistance of earth, irrespective of the earth resistance and condition. Its accuracy was not affected by the resistance of auxiliary prods or leads or by stray AC or DC currents in the earth. The instrument's accuracy was not dependent on the meter, but on the precision calibrated potentiometer. Polarization effects were reduced to a minimum. Unfortunately, this equipment is no longer in production nor is it supported by the manufacturer.

Earth resistance is the resistance of soil to the passage of electric current between two electrodes. Earth is a relatively poor conductor of electricity compared to a normal conductor, i.e. copper or aluminum. But if the area of the path is large enough, resistance can be quite low and the earth can be a good conductor. Earth ground is commonly used as an electrical conductor for system return.

Reason for measuring earth resistance or soil resistivity:

- Determine the effectiveness of grounding grids and connections which are used with electrical systems to protect personnel and equipment.
- Designing groundbeds for Cathodic Protection or determining the necessity for Cathodic Protection.
- Estimate the depth of bedrock, water table, or other geoelectric boundaries.
- Mapping and detecting other geological features.

INVESTIGATION PROCEDURES

We tested resistivity using the Wenner 4-pin method in accordance with ASTM G57. A soil resistance harness manufactured by Universal Rectifiers, Inc. uses 9-pin spacing connections to test soil resistivity at nominal pin spacings of 5’, 10’, 15’, and 20’. The pin spacing on the harness was manufactured with slightly longer spacing between each set of pins to compensate for the multipliers used to convert the measured resistance to resistivity in ohm-cms. The standard multiplier for the Wenner 4-Pin method is 191.51 times the pin spacing. Using slightly longer pin settings result in fixed, even multipliers. For instance, the multiplier used for the 5’ pin spacing using this cable set is 1000 instead of 957.55 because the actual pin spacing is 5.2216-feet instead of 5 feet. The pin spacing depths are increased slightly to provide fixed, even multipliers of 1000, 2000, 3000, and 4000. The soil resistance harness set includes two calibration check circuits to insure integrity of the measurements.

The measurements were taken in front yard of our office building, and other locations in north central Texas. Comparative measurements were taken for the depth of 5’, 10’, 15’, and 20’ in low to medium soil resistivity environments. High to very high resistivity soils were simulated in the laboratory using power resistors. All of the meters evaluated in this paper generated an AC signal output and could be capable of producing crosstalk in the cable set.

RESULTS

Six sets of testing results are shown in the following tables 1 through table 6. The errors are widespread between individual meters. Meter number 1 performed very well for lower and higher resistivity soils. It performs badly for moderate resistivity soils. For medium resistivity soils, the maximum error between pre-fabricated cable and individual leads was 12.6%. Meter number 2 performed badly except very high resistivity soils. The maximum error between the pre-fabricated cable and individual leads was 70.6%. Meter numbers 2 and 3 performed very well for wide range of soil conditions. The maximum error for meter number 3 was 2.857% and for meter number 4 was 2.778%. Errors in the range of one or two percent are considered acceptable for field measurements. Errors in the range of two to three percent, while not ideal, are tolerable. Those greater than three percent are not acceptable.

Key to Color Bands:

Error less than 1%

Error 1% to 2%

Error 2% to 5%

Error 5% or greater

		METER I			METER II		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	0.74	0.74		0.36	0.63	
	ρ	740.00	740.00	0.000	360.00	625.00	73.61
10	R	0.51	0.51		0.42	0.55	
	ρ	1,020.00	1,020.00	0.000	840.00	1,100.00	30.95
15	R	0.36	0.36		0.35	0.46	
	ρ	1,080.00	1,080.00	0.000	1,050.00	1,380.00	31.43
20	R	0.34	0.34		0.31	0.33	
	ρ	1,360.00	1,360.00	0.000	1,240.00	1,320.00	6.45
		METER III			METER IV		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	0.76	0.75		0.904	0.898	
	ρ	760.00	750.00	-1.316	904.00	898.00	-0.664
10	R	0.53	0.52		0.532	0.529	
	ρ	1,060.00	1,040.00	-1.887	1,064.00	1,058.00	-0.564
15	R	0.38	0.37		0.403	0.401	
	ρ	1,140.00	1,110.00	-2.632	1,209.00	1,203.00	-0.496
20	R	0.35	0.34		0.354	0.352	
	ρ	1,400.00	1,360.00	-2.857	1,416.00	1,408.00	-0.565

Table 1: Soil Resistivity Meters Comparison for Test Site Number 1

		METER I			METER II		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	3.79	3.81		3.71	3.72	
	ρ	3,790.00	3,810.00	0.528	3,710.00	3,720.00	0.270
10	R	2.24	2.25		2.21	2.20	
	ρ	4,480.00	4,500.00	0.446	4,420.00	4,400.00	-0.452
15	R	3.79	1.84		1.82	1.78	
	ρ	3,790.00	5,520.00	0.000	5,460.00	5,340.00	-2.198
20	R	2.24	1.32		1.29	1.31	
	ρ	4,480.00	5,280.00	0.000	5,160.00	5,240.00	1.550
		METER III			METER IV		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	3.80	3.81		3.78	3.75	
	ρ	3,800.00	3,810.00	0.263	3,780.00	3,750.00	-0.794
10	R	2.28	2.26		2.76	2.74	
	ρ	4,560.00	4,520.00	-0.877	5,520.00	5,480.00	-0.725
15	R	1.86	1.85		1.79	1.77	
	ρ	5,580.00	5,550.00	-0.538	5,364.00	5,319.00	-0.839
20	R	1.33	1.33		1.29	1.28	
	ρ	5320	5320	0.000	5,152.00	5,104.00	-0.932

Table 2: Soil Resistivity Meters Comparison for Test Site Number 2

		METER I			METER II		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	62.90	63.00		62.20	62.50	
	ρ	62,900.00	63,000.00	0.159	62,200.00	62,500.00	0.482
10	R	24.30	24.30		24.00	24.00	
	ρ	48,600.00	48,600.00	0.000	48,000.00	48,000.00	0.000
15	R	7.92	8.21		7.90	8.40	
	ρ	23,760.00	24,630.00	3.662	23,700.00	25,200.00	6.329
20	R	3.39	3.85		3.25	3.30	
	ρ	13,560.00	15,400.00	13.569	13,000.00	13,200.00	1.538
		METER III			METER IV		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	63.40	63.30		63.20	63.20	
	ρ	63,400.00	63,300.00	-0.158	63,200.00	63,200.00	0.000
10	R	24.70	24.50		24.54	24.51	
	ρ	49,400.00	49,000.00	-0.810	49,080.00	49,020.00	-0.122
15	R	8.27	8.00		8.10	8.10	
	ρ	24,810.00	24,000.00	-3.265	24,300.00	24,300.00	0.000
20	R	3.62	3.55		3.60	3.70	
	ρ	14,480.00	14,200.00	-1.934	14,400.00	14,800.00	2.778

Table 3: Soil Resistivity Meters Comparison for Test Site Number 3

		METER I			METER II		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R						
	ρ						
10	R	62.10	62.80		62.00	61.90	
	ρ	124,200.00	125,600.00	1.127	124,000.00	123,800.00	-0.161
15	R	38.40	38.40		37.90	38.10	
	ρ	115,200.00	115,200.00	0.000	113,700.00	114,300.00	0.528
20	R	25.30	24.20		25.00	23.50	
	ρ	101,200.00	96,800.00	-4.348	100,000.00	94,000.00	-6.000
		METER III			METER IV		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R						
	ρ						
10	R	62.50	62.60		62.80	62.90	
	ρ	125,000.00	125,200.00	0.160	125,600.00	125,800.00	0.159
15	R	38.30	38.30		38.40	38.40	
	ρ	114,900.00	114,900.00	0.000	115,200.00	115,200.00	0.000
20	R	24.60	24.30		24.85	24.45	
	ρ	98,400.00	97,200.00	-1.220	99,400.00	97,800.00	-1.610

Table 4: Soil Resistivity Meters Comparison for Test Site Number 4

		METER I			METER II		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	99.20	99.80		101.10	101.10	
	ρ	99,200.00	99,800.00	0.605	101,100.00	101,100.00	0.000
10	R	99.20	99.70		101.10	101.10	
	ρ	198,400.00	199,400.00	0.504	202,200.00	202,200.00	0.000
15	R	99.20	99.80		101.10	101.10	
	ρ	297,600.00	299,400.00	0.605	303,300.00	303,300.00	0.000
20	R	99.20	100.00		101.10	101.10	
	ρ	396,800.00	400,000.00	0.806	404,400.00	404,400.00	0.000
		METER III			METER IV		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	101.00	101.00		101.3	101.30	
	ρ	101,000.00	101,000.00	0.000	101,300.00	101,300.00	0.000
10	R	101.00	101.00		101.3	101.30	
	ρ	202,000.00	202,000.00	0.000	202,600.00	202,600.00	0.000
15	R	101.00	101.00		101.3	101.30	
	ρ	303,000.00	303,000.00	0.000	303,900.00	303,900.00	0.000
20	R	101.00	101.00		101.3	101.30	
	ρ	404,000.00	404,000.00	0.000	405,200.00	405,200.00	0.000

Table 5: Soil Resistivity Meters Comparison for Test Site Number 5

		METER I			METER II		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	998.00	999.00		1,000.00	1,010.00	
	ρ	998,000.00	999,000.00	0.100	1,000,000.00	1,010,000.00	1.000
10	R	998.00	997.00		1,000.00	1,010.00	
	ρ	1,996,000.00	1,994,000.00	-0.100	2,000,000.00	2,020,000.00	1.000
15	R	998.00	993.00		1,000.00	1,010.00	
	ρ	2,994,000.00	2,979,000.00	-0.501	3,000,000.00	3,030,000.00	1.000
20	R	998.00	996.00		1,000.00	1,010.00	
	ρ	3,992,000.00	3,984,000.00	-0.200	4,000,000.00	4,040,000.00	1.000
		METER III			METER IV		
DEPTH (FT.)		INDIVIDUAL LEADS	ON CABLE	% ERROR	INDIVIDUAL LEADS	ON CABLE	% ERROR
5	R	993.00	993.00		998.00	997.00	
	ρ	993,000.00	993,000.00	0.000	998,000.00	997,000.00	-0.100
10	R	993.00	993.00		998.00	997.00	
	ρ	1,986,000.00	1,986,000.00	0.000	1,996,000.00	1,994,000.00	-0.100
15	R	993.00	994.00		998.00	997.00	
	ρ	2,979,000.00	2,982,000.00	0.101	2,994,000.00	2,991,000.00	-0.100
20	R	993.00	993.00		998.00	997.00	
	ρ	3,972,000.00	3,972,000.00	0.000	3,992,000.00	3,988,000.00	-0.100

Table 6: Soil Resistivity Meters Comparison for Test Site Number 6

CONCLUSIONS

As with any other electrical test equipment, it is very important to assure the accuracy of the data that is collected. For soil resistivity measurements, this begins with an instrument that is in current calibration. When using a pre-measured cable set, it is imperative that the tester confirms compatibility between the instrument and the cable set over a wide range of conditions. Otherwise, design calculations based on these data may be of little value.