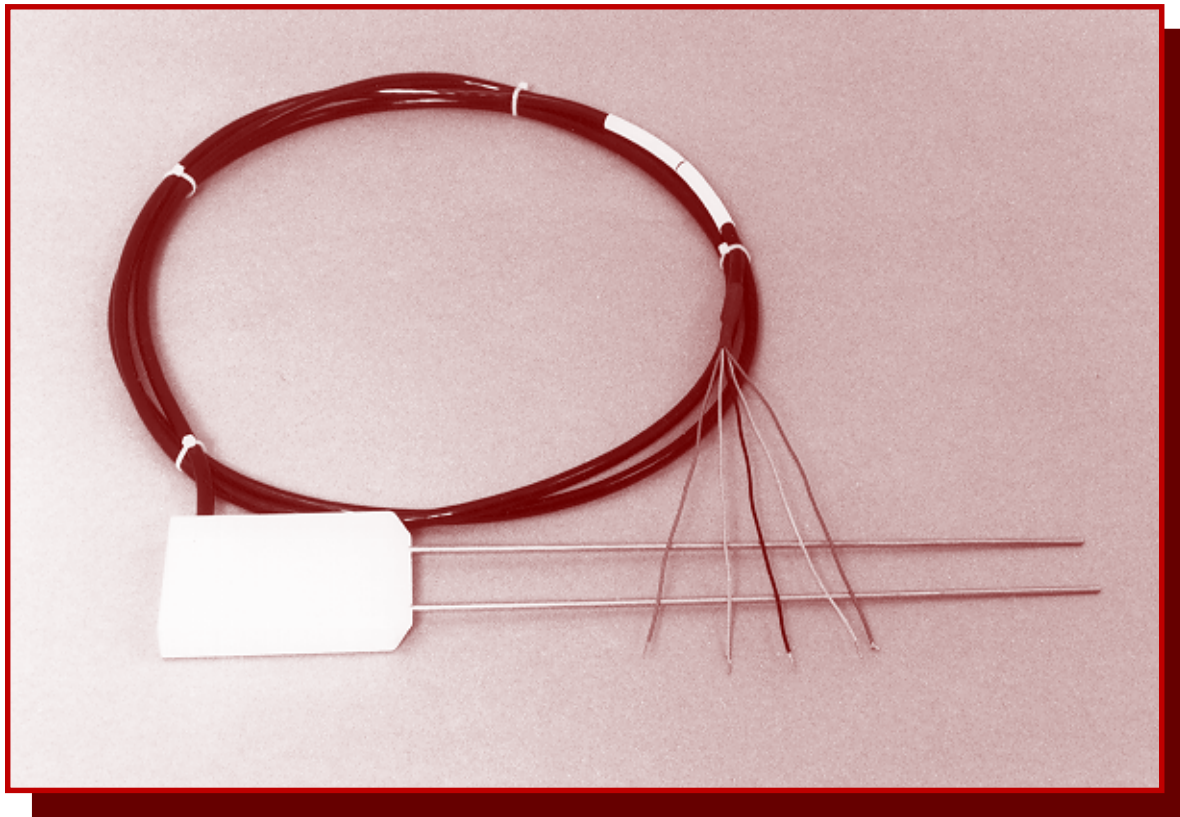


Campbell Water Content Reflectometer

Evaluation in Compacted Road Soils



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6E62KB9—TDR Forest Floor
Moisture Measurement

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Introduction

The Campbell Scientific, Inc., Model CS615 water content reflectometer (Figure 1) is an electronic probe intended to measure moisture in soils and other porous media. It's designed to work with the Campbell data loggers and can also work with most personal computers. The Model CS615 is relatively inexpensive, costing just \$205. The typical instruments that employ time domain reflectometry (TDR) cost several thousand dollars. This project was intended to determine if MTDC could find a low-cost alternative to time domain reflectometers.

The CS615 and TDR instruments measure moisture content by sensing changes in the dielectric constant of the material. Free water has a dielectric constant about 20 times greater than that of mineral matter, so any water increases the observed dielectric constant. The probes are similar for both methods and are inserted into the material being measured. The CS615 has two stainless steel rods 30 cm long, 3.3 mm in diameter spaced 3.2 cm apart. This is a common size and configuration for TDR probes. However, the size and number of rods used in TDR probes varies. The circuitry employed and the method of sensing the relative dielectric constant are considerably different for the two types of instruments.

With TDR a fast-rise time pulse applied to one end of the probe rods propagates along the rods and is reflected back at the far end of the rods. The time that the pulse travels down the rods and back is related to the dielectric constant of the media surrounding the rods. The travel time increases as the dielectric constant increases with increasing moisture content. The TDR method can produce highly accurate soil moisture measurement. However,

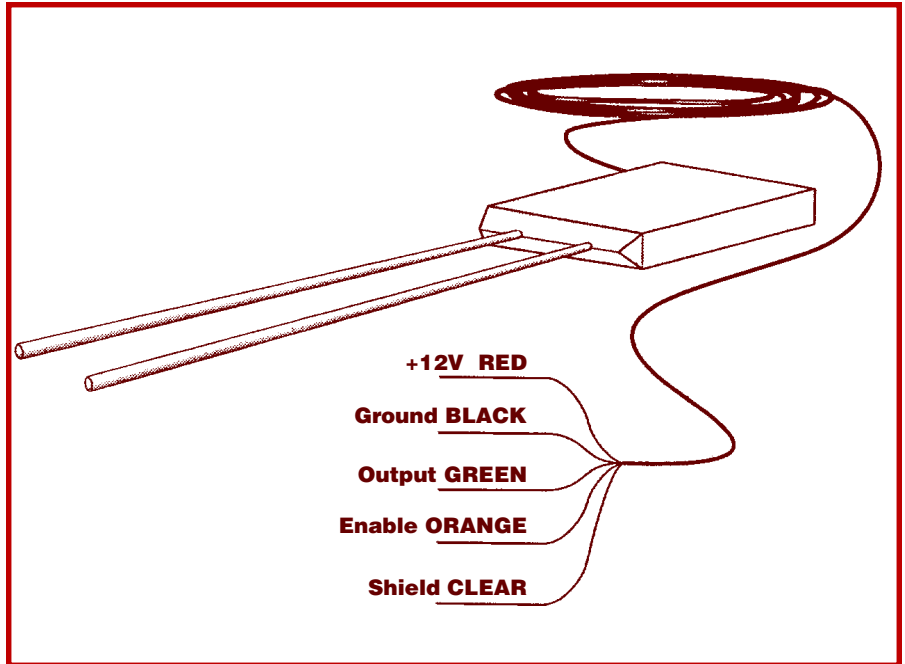


Figure 1—Model CS615 Water Content Reflectometer.

the electronics needed to implement TDR are expensive because they require very high-speed, accurate circuits.

The Campbell CS615 uses an astable multivibrator circuit that operates over a range of 23 to 47 MHz. The oscillation frequency depends on the dielectric constant of the media surrounding the probe rods. Higher moisture content (larger dielectric constant) lowers the operating frequency. Inexpensive digital circuits divide the output frequency of the multivibrator down to 700 to 1,400 Hz. The output is a square wave with a peak output of 5 volts.

The two probe rods attach directly to the circuit card. A shielded four-conductor cable connects the circuit card to a power source and provides a con-

trol signal to conserve battery power by powering down the circuit when it is not in use. Also, the square-wave output is present on one conductor. The circuit board is encapsulated in epoxy.

Accuracy is specified at +/-2% when the CS615 is calibrated for a specific soil. The accuracy when using the general calibrations depends on soil texture and mineral composition. The CS615 is predominantly affected by changing dielectric constant due to changing water content, but it is also affected by electrical conductivity. Free ions in soil solution provide electrical conduction paths that attenuate of the signal applied to the probe rods. The CS615 is also sensitive to temperature. Temperature compensation can enhance accuracy.

Test Procedure

A test was designed to determine the accuracy of the Campbell CS615 probe when used in highly compacted road soils. A steel mold (Figures 2a, 2b, and 2c) was constructed to hold the soil samples and contain the probe rods. The rods were surrounded with enough material to prevent the mold sides from influencing the measurements. The soil was compacted into the mold in four lifts to obtain uniform compaction.

Test samples were prepared as follows. Water was added to dry soil by weight to obtain a target gravimetric moisture content. The sample was mixed thoroughly and divided by weight into four batches to be compacted into the mold. The first batch was placed into the mold and carefully leveled to a uniform depth. The compaction plate was placed on the layer. A press forced the plate into the mold, compacting the batch to a predetermined thickness to obtain the target density and the target volumetric moisture. The second batch that was half the weight of the first was compacted to fill the mold to the level where the probe was placed. Another half-weight layer was compacted. Finally, the last full-weight layer was added.

The measured volumetric moisture was recorded and observed for up to several days to determine any change in reading with time. Also, several samples were placed in a freezer and frozen to observe the measured moisture.

After the test run, the mold was disassembled and the two center soil lifts nearest the probe were removed, weighed, dried, weighed again, and the gravimetric moisture was calculated. This moisture content was used to calculate the actual volumetric moisture content.

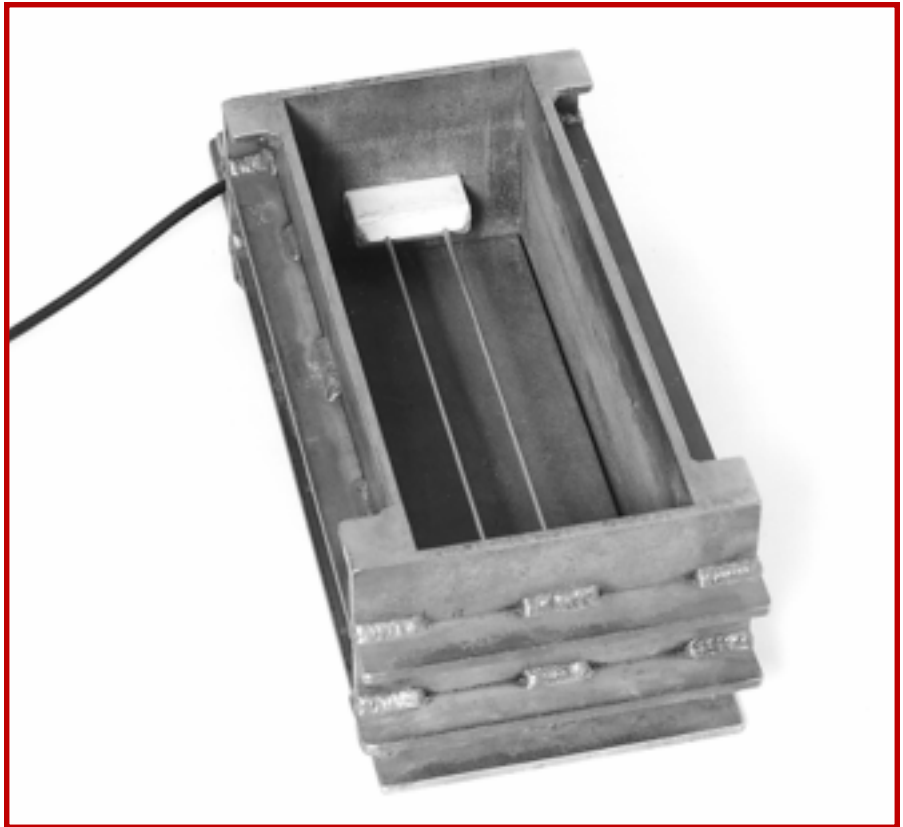


Figure 2a—CS615 probe in the mold.

The calibration curve supplied by Campbell Scientific for electrical conductivity of less than 1 dS m^{-1} was used. The equation for this curve is: $\theta_v(\tau) = -0.187 + 0.037\tau + 0.335\tau^2$. Where θ_v is the volumetric water content on a decimal fraction basis and τ is the CS615 output period in milliseconds. No temperature compensation was used.

The initial test plan was to evaluate the CS615 in three soil types at three compaction densities and five volumetric moisture contents. The soil types were silt-sand, clay-sand, and aggregate $\frac{1}{2}$ -inch minus.

The test mold with the sample and the CS615 were moved to a freezer and cooled to -8.2°C for the first five test runs. The data logger had to be disconnected when moving the test samples into or out of the freezer. This caused spikes in the data graphs.

For three test runs, a thermocouple was placed in the test sample near the probe rods to observe the effect of temperature on the CS615 reading.

A few tests were conducted using a Tektronix 1502B TDR and a typical 2-rod probe (Figure 3) to provide a control reference.

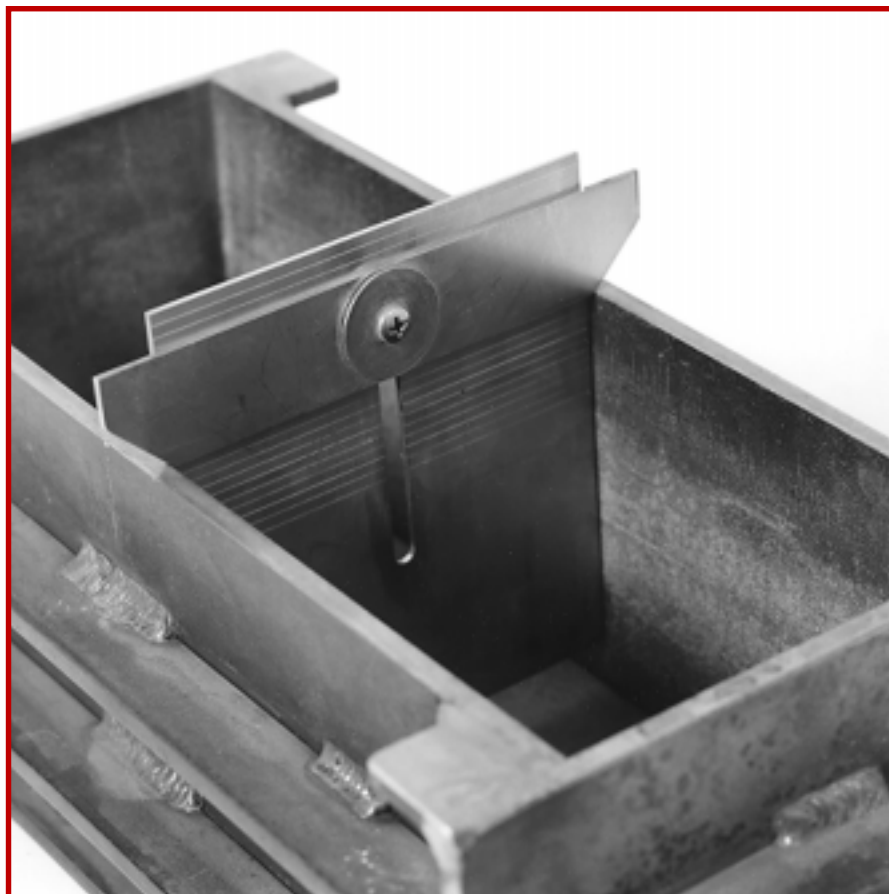


Figure 2b—Soil-leveling tool in the mold.



Figure 2c—Components used to prepare and remove soil samples from the mold.



Figure 3—Tektronix TDR with two-rod probe.

Test Results

Twelve runs were conducted using a silt-sand soil and the Campbell CS615. Three runs were conducted in clay-sand soil with the CS615. Nine runs were conducted in the silt-sand soil using the Tektronix TDR.

Figure 4 shows the Tektronix TDR readings at three different densities and three different moisture contents. The readings were derived using the standard TDR calibration curve (Topp, Davis, and Annan 1980). All readings are higher than the actual moisture. A straight line can be fit through the points corresponding to each density. The higher the density, the more the line is offset positive. Table 1 compares TDR readings to actual moisture.

Table 1—TDR readings compared to actual moisture.

TDR Reading	Density (Grams/cc)	Actual Moisture (Percent)	Error (Percent)
0.15	1.62	12	-3
	1.68	11	-4
	1.78	9.8	-5.2
0.20	1.59	17.2	-2.8
	1.68	16	-4
	1.87	13.8	-6.2
0.30	1.59	27.1	-2.9
	1.68	26	-4
	1.88	22	-8

Volumetric vs. True TDR

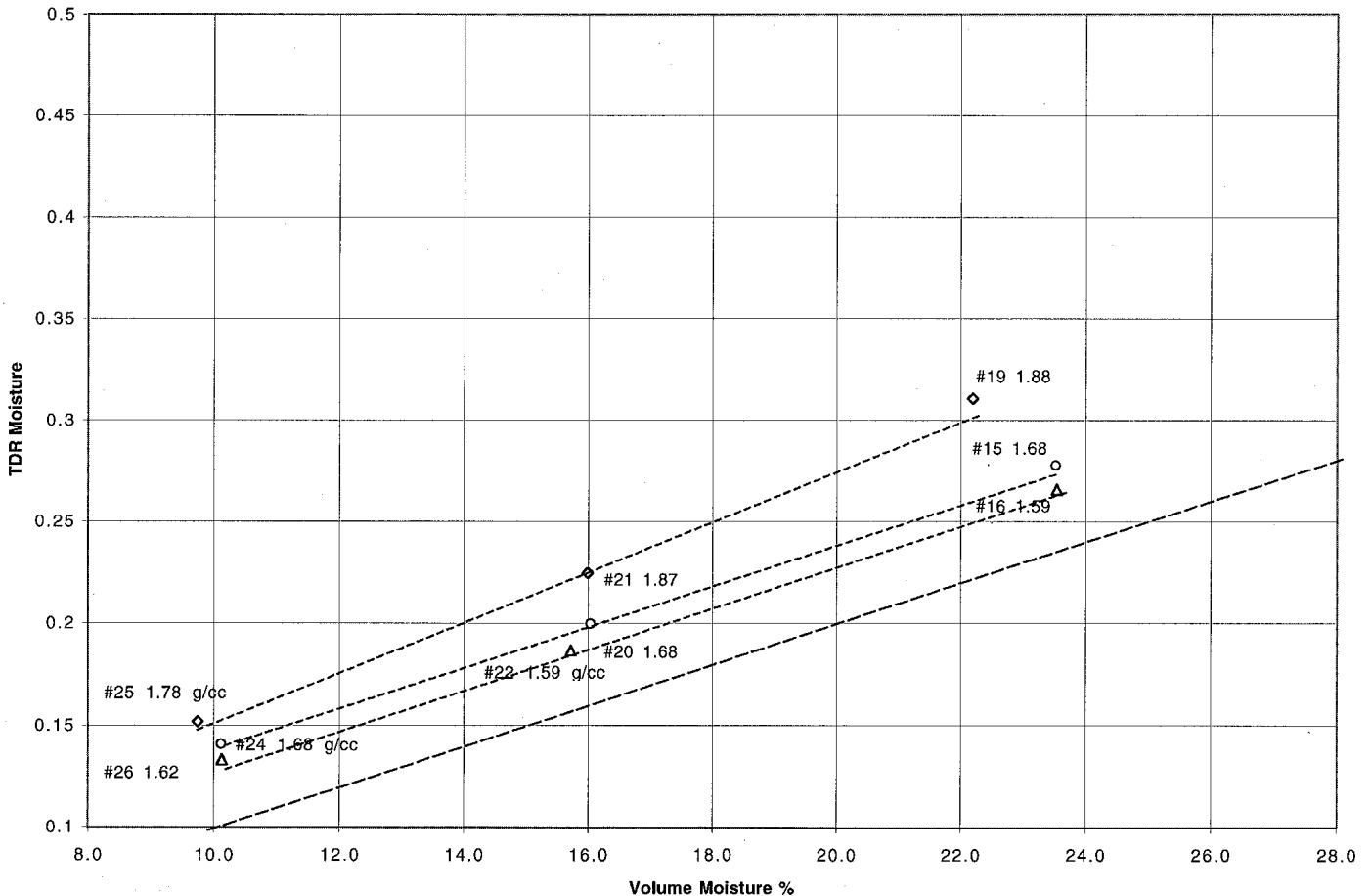


Figure 4—Tektronix TDR readings at three different densities and moisture contents. If the meter were perfectly accurate, all points would be on the lower line. The three upper lines show the best fit for readings for each of the three densities.

Figure 5 shows the Campbell Scientific CS615 readings for several different densities and moisture contents. Note point numbers 11, 13, and 27 clustered near 15.5% volume moisture, and 0.39 CS615 moisture for high-density material. The CS615 readings were much higher than the actual moisture. The moisture reading for point 28, at a much lower density and about the same true moisture, was considerably closer to the true moisture value.

Figure 6 shows the freeze-thaw cycle for Test Run No. 4 with the CS615. A section of the graph from 22:00 to 10:00 was removed to expand the remainder of the graph. The removed portion is a straight line. The freeze-thaw cycle had little effect on either the density or the CS615 reading.

The readings of the frozen soil are considerably lower (0.08) than the readings of soil at 21 °C (.25). This

change is because the dielectric constant of ice is considerably smaller than that of water, 3.2 compared to 80. The transition from water to ice crystals and back is gradual as freezing and thawing occurs, explaining the slow change in the observed CS615 reading (Spaans and Baker 1995).

Figures 7, 8, and 9 show the CS615 readings versus temperature. The temperature coefficient given by

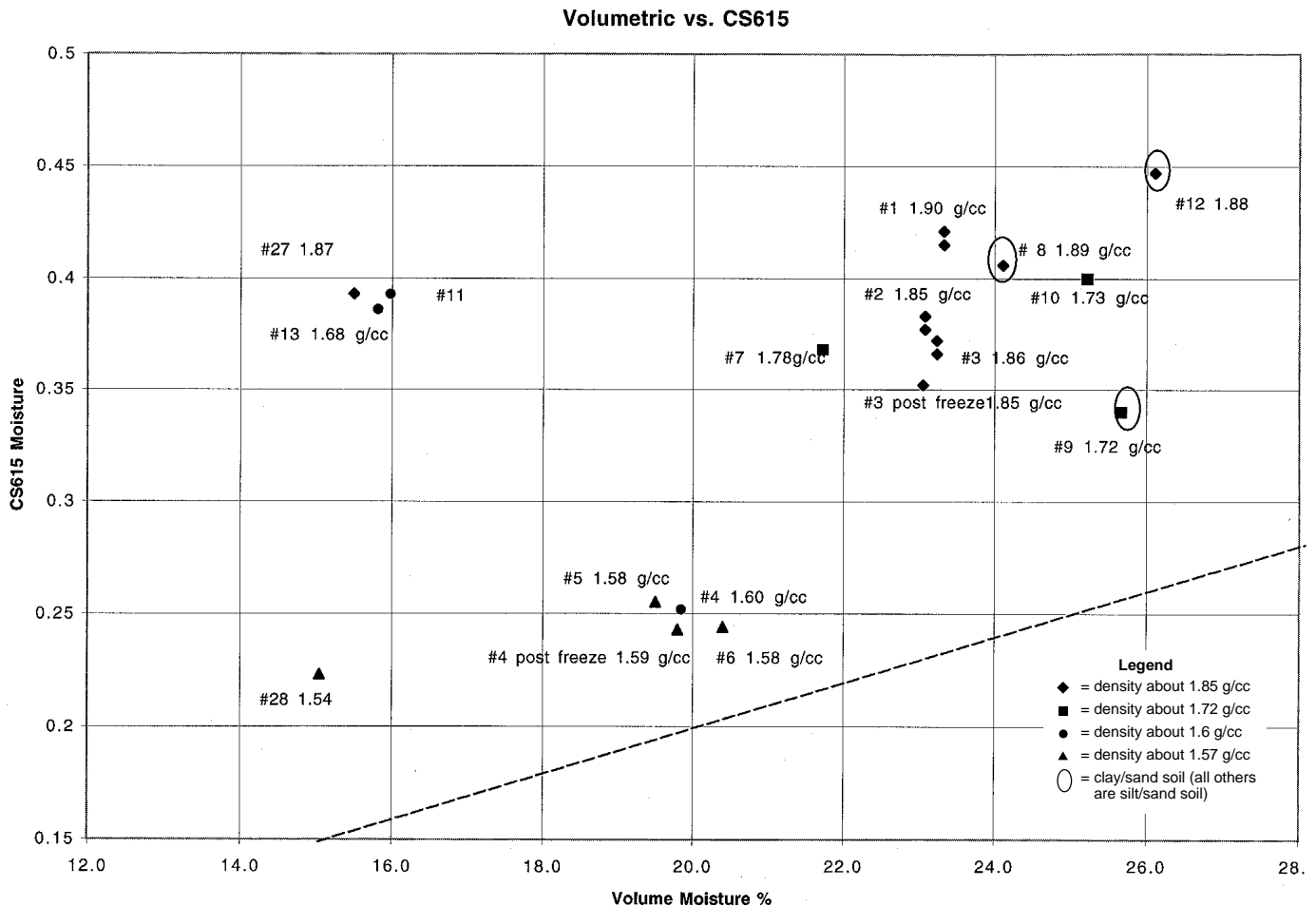


Figure 5—Campbell Scientific CS615 readings for several different densities and moisture contents. If the meter were perfectly accurate, all points would be on the line.

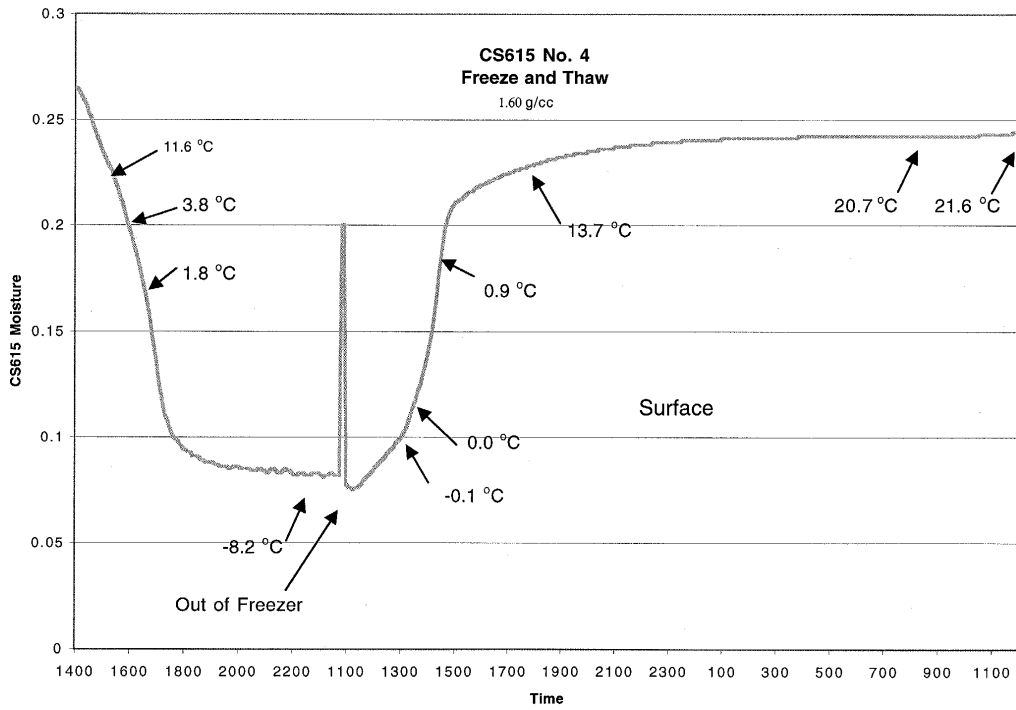


Figure 6—Freeze-thaw cycle for Test Run No. 4 with the CS615.

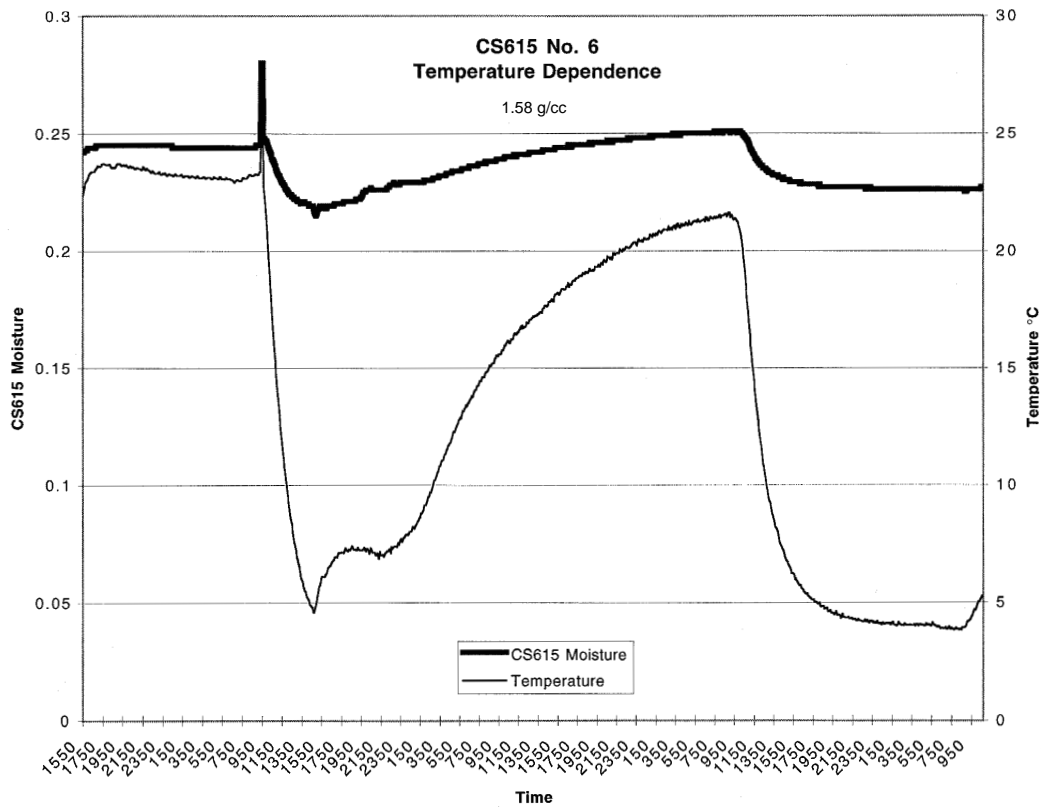


Figure 7—CS615 readings versus temperature at low density (1.58 g/cc).

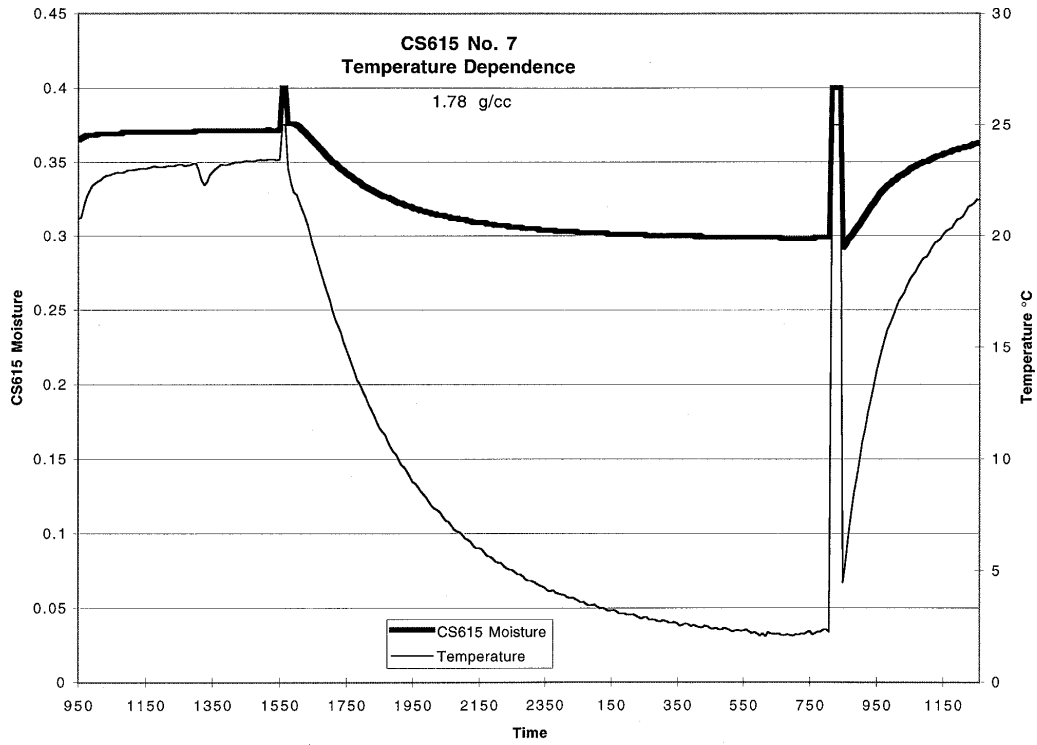


Figure 8—CS615 readings versus temperature at medium density (1.78 g/cc).

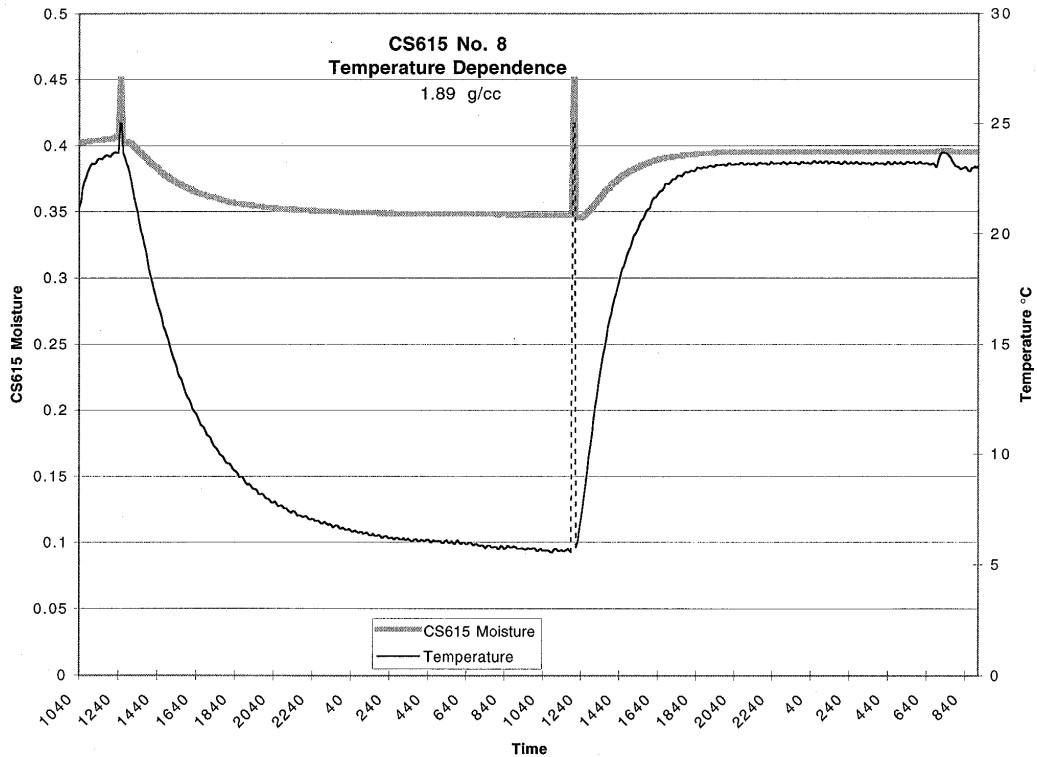


Figure 9—CS615 readings versus temperature at high density (1.89 g/cc).

Campbell Scientific is: $\text{Coef}_{\text{temperature}} = -3.46 * 10^{-4} + 0.019 \theta_v - 0.045 \theta_v^2$.
 Compensation for the calibration offset was applied to the CS615 data. The Campbell Scientific and measured temperature coefficients are shown in Table 2.

Table 2—Campbell Scientific and measured temperature coefficients.

Test No.	Volumetric Moisture	Density (Grams/cc)	Campbell Temp. Coef. $\text{m}^3\text{m}^{-3} \text{ } ^\circ\text{C}^{-1}$	Measured Temp. Coef. $\text{m}^3\text{m}^{-3} \text{ } ^\circ\text{C}^{-1}$
6	20.4	1.58	0.00166	0.00130
7	21.7	1.78	0.00166	0.00225
8	24.1	1.89	0.00162	0.00196

Conclusions

The Tektronix TDR data were consistent and reasonable. Higher densities caused the readings to be higher. Other researchers have reported this relationship (Dirksen and Dasberg 1993). For high accuracy, a calibration curve for the corresponding density would have to be used.

The Campbell Scientific CS615 data showed considerable error in highly compacted material. The readings at 15.5% and 24% actual volumetric moisture were essentially the same. Therefore, the CS615 could not be calibrated.

There was good repeatability of the data. This would tend to rule out the possibility of an error in the testing.

Because the CS615 performed so badly in highly compacted material, the testing was terminated without completing all planned calibration runs. The CS615 is not suitable for use in highly compacted road soils.

The freeze-thaw cycle graph (Figure 6) is interesting because TDR-measured moisture content alone might be used to indicate the presence of spring breakup conditions. The rapid rise in observed moisture accompanied by high moisture levels would indicate that the ice has changed to liquid water and that the road material is saturated and unstable.

The equation that Campbell Scientific provides for the temperature coefficient is reasonable. Considering the very limited amount of test data, the agreement between the equation values and test data values is good. Any error in temperature coefficient is very small compared to the calibration offset caused by changes in material density.

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Dirksen, C.; Dasberg, S. 1993. Improved calibration of time domain reflectometry soil water content measurements. *Soil Science Society of America Journal*. 57(3): 660-667.

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Describes tests using the Campbell Scientific, Inc., Model CS615 water content reflectometer to measure moisture in compacted road soils. The CS615 costs just \$205, while instruments that employ the more accurate time domain reflectometry system cost several thousand dollars. Testing showed that the CS615 is not suitable for use in highly compacted road soils.

Keywords: electrical moisture meters, instruments, moisture content, moisture meters, spring breakup

About the Author

Dave Gasvoda has a bachelor's degree in electrical engineering from Montana State University. He joined the Missoula Technology and Development Center in 1969 and has worked on a wide variety of projects since then. Electronic devices that he designed have saved Forest Service employees backbreaking labor. Dave has been awarded one patent and has another pending.

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