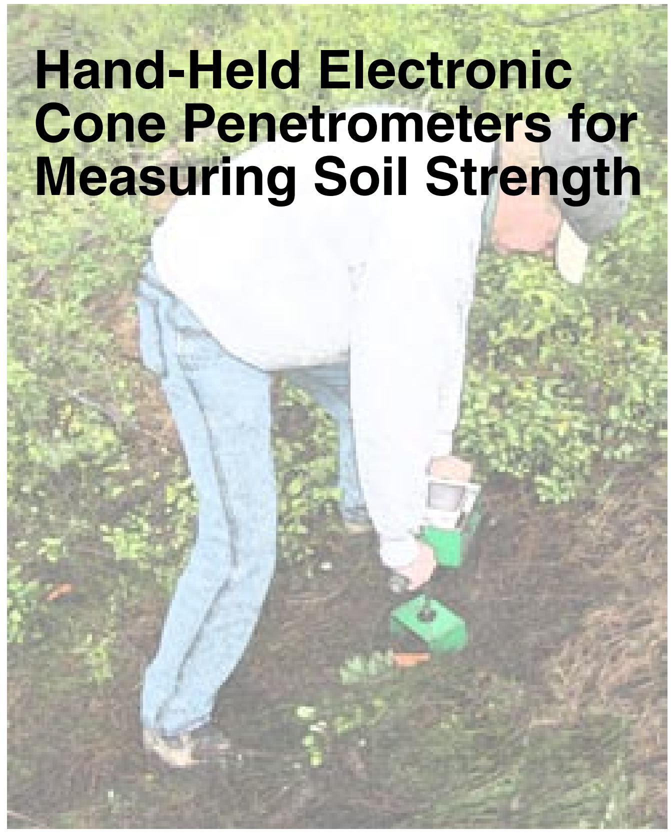
Hand-Held Electronic Cone Penetrometers for Measuring Soil Strength



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Missoula, MT

2E22E60—Soil Strength Tester

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Highlights...

- Soil penetrometers can help measure soil strength. Forest management activities that require the use of heavy equipment can increase soil strength, making it difficult for roots to grow.
- Older mechanical cone penetrometers traditionally used to measure soil strength require two persons to operate.
- Newer hand-held electronic cone penetrometers can be operated by one person and can probe 500 mm deep in 17 s, compared to about 5 min for a dynamic cone penetrometer.

Contents

Acknowledgments

Leonard Roeber (deceased), Boise National Forest, Idaho City, ID

David Young, Pacific Southwest Research Station, Redding, CA

Richard E. Miller, Forestry Sciences Laboratory, Olympia, WA

Greg Ruark, USDA National Agroforestry Center, Normal, AL

Special thanks to the Coeur d'Alene Nursery and to the equipment fabrication shop and publications staff at MTDC.

Introduction

Humans have been probing the ground since they could hold sticks, but only in more recent times have their probes been scientific. Researchers interested in studying soil stratification probed the ground with pointed rods during the early 1900s. A more refined instrument called a *cone penetrometer* was invented in the Netherlands during the mid 1930s to measure soil strength.

Cone penetrometers measure soil penetration resistance or soil strength encountered at various depths as a cone-shaped object is pushed steadily into the ground. Advances in electronics and software have expanded penetrometer functions to include such features as moisture and temperature sensors, soil structure analysis, video, and soil composition analysis. These high-tech penetrometers are used mainly in environmental and geotechnical site investigation. They are large instruments, usually mounted on heavy-duty truck frames or tracked vehicles (figure 1). The cones are driven into the ground at consistent speeds to great depths.

Because these machines are too large and expensive for simple field applications, the Missoula Technology and Development Center (MTDC) evaluated three hand-held electronic cone penetrometers. Until recently, similar penetrometers were comprised of a dial indicator with a stress ring connected to a round rod with scaled depth markings. The rod has a cone-shaped tip at one end and a handle for pushing the cone into the ground on the other end (figure 2). Using these penetrometers was a cumbersome operation best completed by two people; one to push the penetrometer into the ground and read the force on the dial indicator, and the other to record probe depth and force.

Figure 1—This track-mounted, hydraulically driven soil penetrometer, manufactured by AMS, Inc., is designed for environmental and geotechnical site-investigation studies. (Photo courtesy of AMS, Inc.)

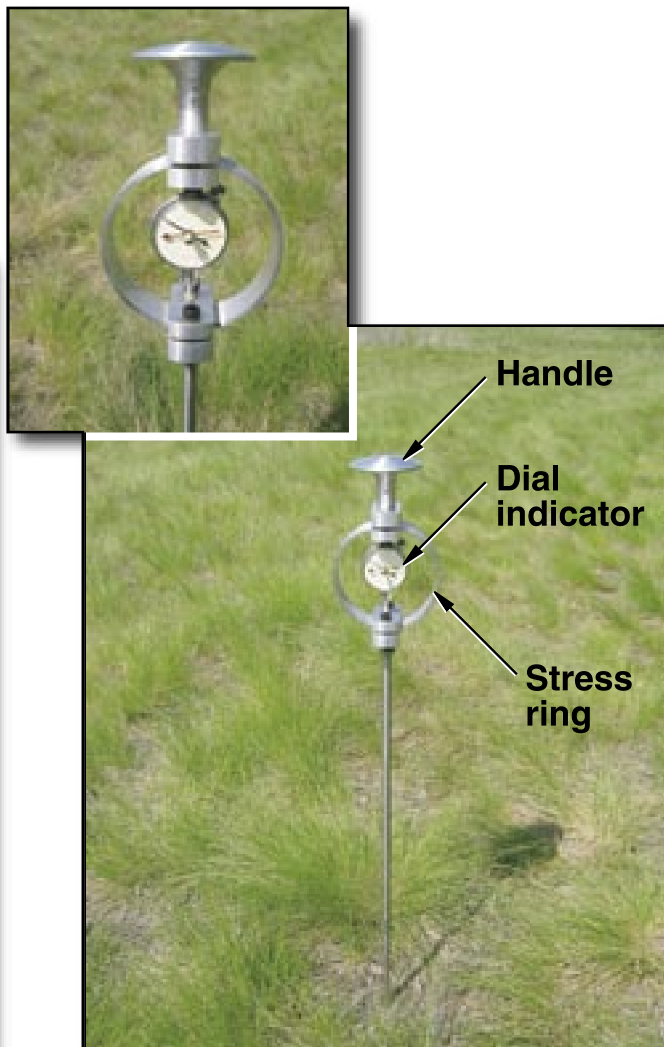
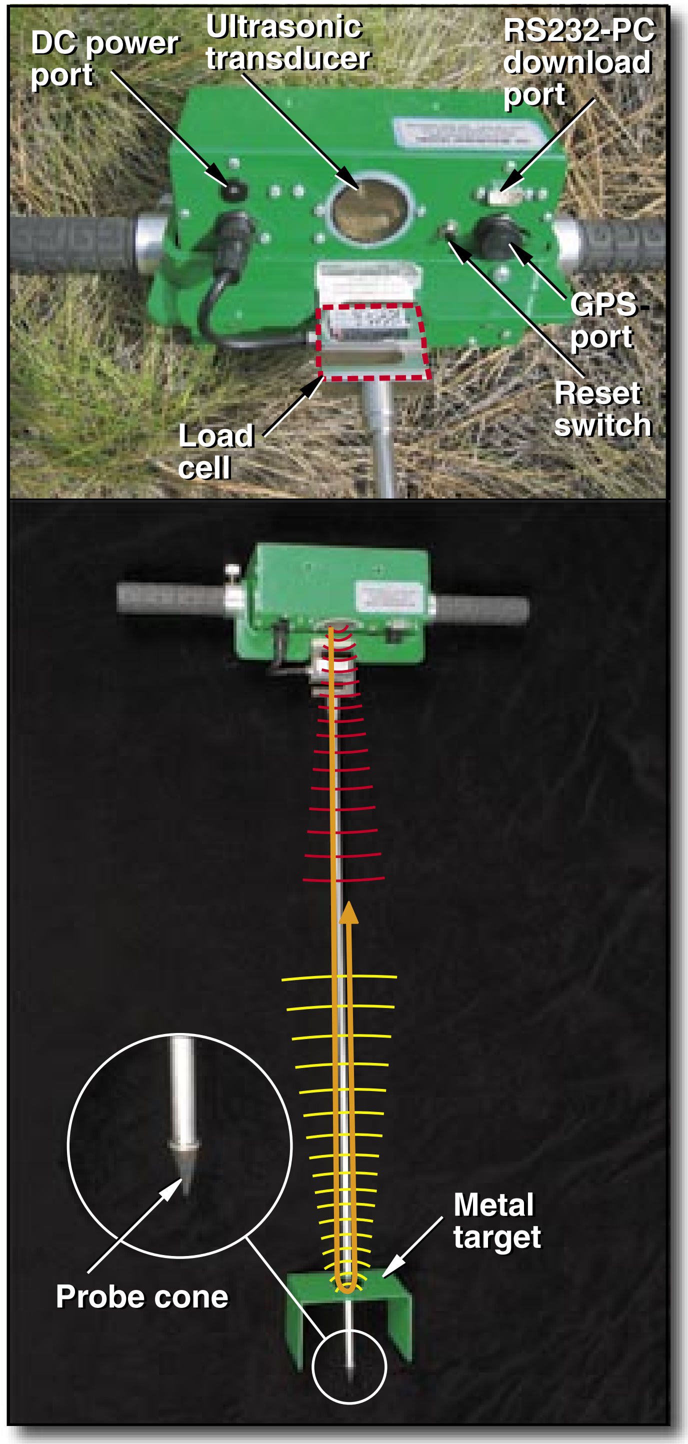


Figure 2—Mechanical cone penetrometers have been used for decades. A dial indicator mounted inside a metal stress ring shows the force exerted on the handle of this vintage penetrometer.

The hand-held electronic cone penetrometers evaluated by MTDC (figure 3) can be operated by a single person. Each model electronically records the force required to push the probe into the ground and depth reading for computer download and analysis. As the probe is pushed into the ground, the force recorded by the electronic load cell is used to calculate the cone index, a number derived from the frictional forces on the cone's surface as it is pushed into the ground. The cone index is a relative indicator of the soil's strength, typically recorded in kilopascals or pounds per square inch.

Figure 3—The three hand-held electronic cone penetrometers tested by MTDC were the Rimik CP40 (left); the Eijkelkamp Penetrologger (center); and the Spectrum Field Scout SC–900 (right).

The penetrometer is able to calculate the probe's depth by determining the time it takes to bounce a signal from an ultrasonic transducer off a metal target on the ground, and back to the transducer (figure 4). A datalogger records the soil's strength and the probe's depth. For accurate readings, the penetrometer must be inserted into the ground at a steady speed of about 30 mm/s.



Figures 4—The operating components of a typical hand-held cone penetrometer. The metal target bounces a signal back to the transducer, allowing the penetrometer to calculate the probe's depth. These photos show the Rimik CP40.

Typical Uses of Hand-Held Penetrometers

Although penetrometers are very useful for certain applications, the data show trends, but not exact measures of soil density or compaction. The penetrometer provides very accurate information on soil strength, or resistance to penetration, to some depth. However, strength measurements are affected by moisture, porosity, and rock content.

When combined with other information, such as soil moisture, structure, and texture, data from penetrometers can contribute to a more accurate picture of soil properties. Typically, penetrometer readings taken in moist soils are easier to acquire and give more meaningful information than readings taken in dry, hard-packed soils. Penetrometers are best suited for studying soil strengths (resistance to penetration) in comparison studies between areas with similar soil composition and moisture, or in one area where impacts change over time, such as in areas that are farmed or logged.

The agricultural industry has been a leader in using electronic penetrometers. Forest tree nurseries could benefit from information provided by a penetrometer, such as identification of areas of high compaction, plow pans, and clay zones to help determine appropriate irrigation, fertilization, and cultivation practices.

Soil compaction begins to inhibit the root growth of most plants when the soil's strength is about 1,500 kPa. The roots of many plants quit growing when the soil's strength reaches about 2,500 kPa. Penetrometers can help identify these areas faster and easier than standard bulk density tests. More definitive soil testing may be required, but the penetrometer can identify the problem areas.

MTDC initially investigated the use of hand-held electronic cone penetrometers to evaluate how well contractors were compacting the soil around bareroot seedlings planted in holes drilled by augers at the Boise National Forest in Idaho (figure 5). Planting contracts usually specify that each planting hole be filled and compacted by thirds rather than simply being filled and compacted. Roots, rocks, sticks, gopher holes, voids, and the highly compactable granitic soils in the Boise National Forest made it difficult to identify the compacted layers. We concluded that penetrometers are not practical for inspecting proper compaction during tree-planting contracts.

Assessing the impact of logging operations on forest soil compaction is important. Penetrometers may help soil scientists and contracting officers verify that specifications on soil compaction limits are being followed. Indepth Forest Service studies using hand-held electronic cone penetrometers during logging operations have been conducted by the Forestry Sciences Laboratory in Olympia, WA, and the Pacific Southwest Research Station in Redding, CA.

Figure 5—Penetrometer testing in the Boise National Forest near Idaho City, ID.

Operating and Testing Standards

The two main testing standards used in the United States for the design and operation of penetrometers are set by the American Society of Testing Materials (ASTM) and the American Society of Agricultural Engineers (ASAE). ASTM standards are used primarily for heavy, truck-mounted cone penetrometers. The standards for hand-held penetrometers are set by the ASAE. In agriculture and forestry applications, the most common standards are: ASAE S313.3 February 2004, *Soil Cone Penetrometer*, and ASAE EP542 February 1999, *Procedure for Using and Reporting Data Obtained with the Soil Cone Penetrometer.*

ASAE standards require using a steel cylindrical cone with a 30-degree tip. The diameter of the cone is 20.27 mm for soft soils or 12.83 mm for hard soils. The cone should be replaced when the wear exceeds 3 percent of the original diameter. The shaft has a diameter of 15.88 mm for soft soils or 9.53 mm for hard soils.

The amount of force exerted over the cone's surface area is called the *Cone Index* or *CI*, typically recorded in units of kilopascals or pounds per square inch. The cone should be inserted into the ground at a steady rate of about 30 mm/s. It takes practice to become consistent—especially in soil with varying compaction, moisture, types, textures, structures, and voids.

MTDC Penetrometer Evaluations at the Coeur d'Alene Nursery

MTDC evaluators completed side-by-side comparisons of the three hand-held electronic cone penetrometers at the Forest Service's Coeur d'Alene, ID, nursery in late September 2004. These comparisons looked first at how consistently each piece of equipment recorded soil strength and depth, then at the functionality, simplicity, operability, software, hardware, and output of each penetrometer. MTDC evaluators also compared hand-held electronic cone penetrometers with two mechanical penetrometers: the Compact-O-Gauge and a dynamic cone penetrometer. MTDC does not specifically endorse any of the equipment tested and did not test all hand-held electronic cone penetrometers that are available.

The primary goal was to evaluate how well each penetrometer recorded soil strength. MTDC purchased two units, the Rimik CP40 and the Spectrum Field Scout SC–900. The Eijkelkamp Penetrologger was borrowed from Soilmoisture Equipment Corp.

Models, Specifications, and Prices

Table 1 shows the specifications and costs of the three hand-held electronic cone penetrometers tested by MTDC.

Table 1—Manufacturers, specifications, warranties, and purchase prices for the three hand-held electronic cone penetrometers tested by MTDC. The Rimik Model CP40, which was tested, has been replaced by the CP40II.

	CP40	Penetrologger	Field Scout SC–900
Manufacturer	Agridry Rimik PTY LTD	Eijkelkamp Agrisearch Equipment	Spectrum Technologies, Inc.
Units displayed	Metric only	Metric only	Metric or English
Depth range	0–600 mm (24 in)	0–800 mm (32 in)	0–450 mm (18 in)
Pressure range	0–5,500 kPa (798 psi)	0–10,000 kPa (1,450 psi)	0–7,000 kPa (1,000 psi)
Maximum force	75 kg (165 lb)	102 kg (225 lb)	95 kg (210 lb)
Datalogger capacity (measurements)	2,047	500	772 without GPS, 579 with GPS
Weight	3.9 kg (8.6 lb)	2.9 kg (6.39 lb)	1.25 kg (2.75 lb)
Resolution			
Depth	1 mm (0.04 in)	10 mm (0.39 in)	25 mm (1 in)
Pressure	1 kPa (0.15 psi)	1 kPa (0.15 psi)	35 kPa (5 psi)
Accuracy			
Depth	±1 mm (±0.04 in)	±10 mm (± 0.39 in)	±12.5 mm (± 0.5 in)
Pressure	±2.24 kPa (±0.32 psi)	±2.0 kPa (±0.29 psi)	±103 kPa (±15 psi)
GPS compatible?	Yes	No	Yes
Speed alarm	Yes	Yes	No
Power (batteries)	6-V gel cell, rechargeable	(2) D-size, nickel-cadmium	(2) AA alkaline
Display	Graphic LCD	Graphic LCD	16 character, 2-line LCD
Warranty	6 mo	1 yr	1 yr
Cost (as of 3/15/2005)	$5,100 (CP40II)	$5,200	$1,495

Repeatability Tests

Each penetrometer was tested for consistency in recording soil strength and depth by probing the ground in seven locations about 300 mm apart, while maintaining the recommended probe insertion speed of 30 mm/s. Figures 6, 7, and 8 show the results from each of the three penetrometers. The top 100 mm of soil showed very little resistance because the soil had been cultivated to this depth. A hardpan layer is at a depth of 350 to 400 mm.

The Rimik CP40 results are the most consistent. The graph of the Eijkelkamp Penetrologger test looks a little erratic in the lower half of the soil profile. Results of the Spectrum Field Scout SC–900 appear smoother than those of the Eijkelkamp Penetrologger, but the variability widens below 200 mm. The depth range of the three tested units varies from 450 to 800 mm as shown in table 1.

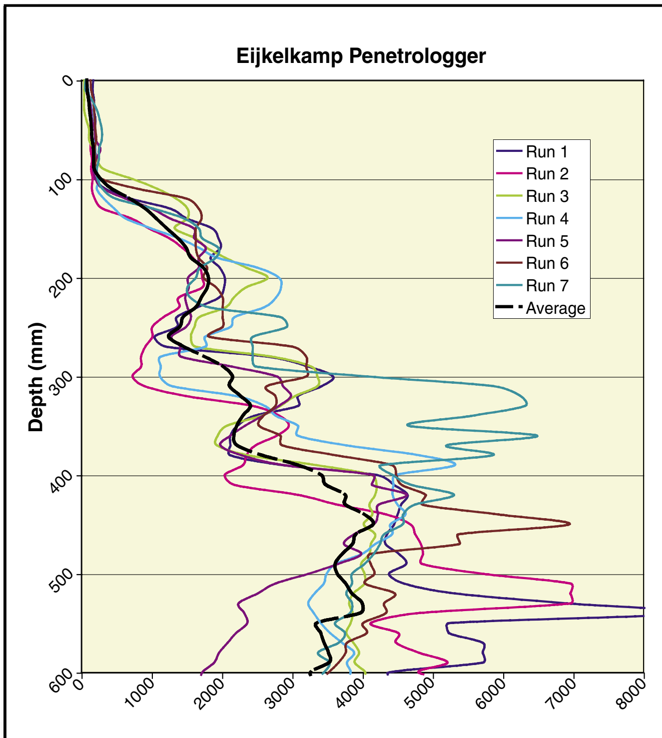


Figure 7—Repetition testing of the Eijkelkamp Penetrologger. The first 100 mm of soil was weak because of recent tillage in the test field. The Eijkelkamp Penetrologger displays metric units.

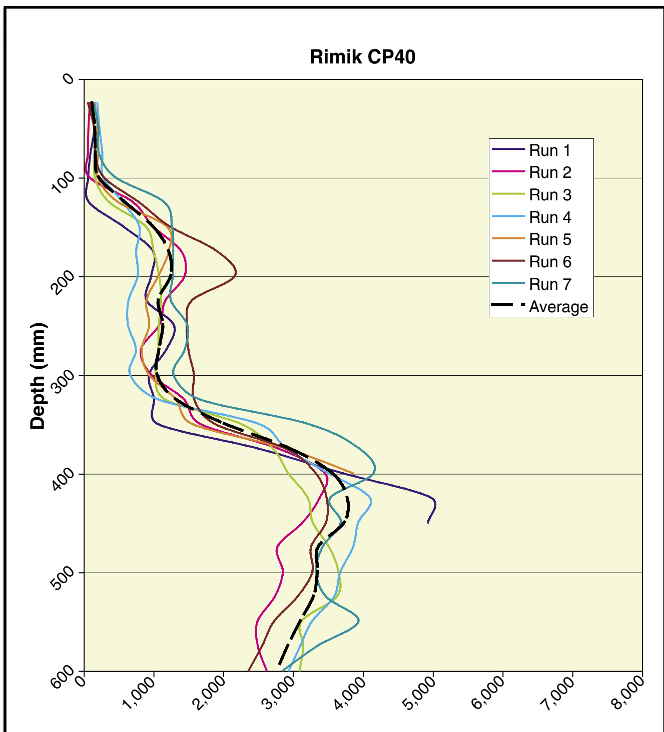


Figure 6—Repetition testing of the Rimik CP40 shows the unit's consistency in documenting soil strength at various depths. Even though the runs were conducted about 300 mm from each other, some variation in readings can be expected because of differences in ground conditions, equipment tracks, and operator inconsistency. The Rimik CP40 displays metric units.

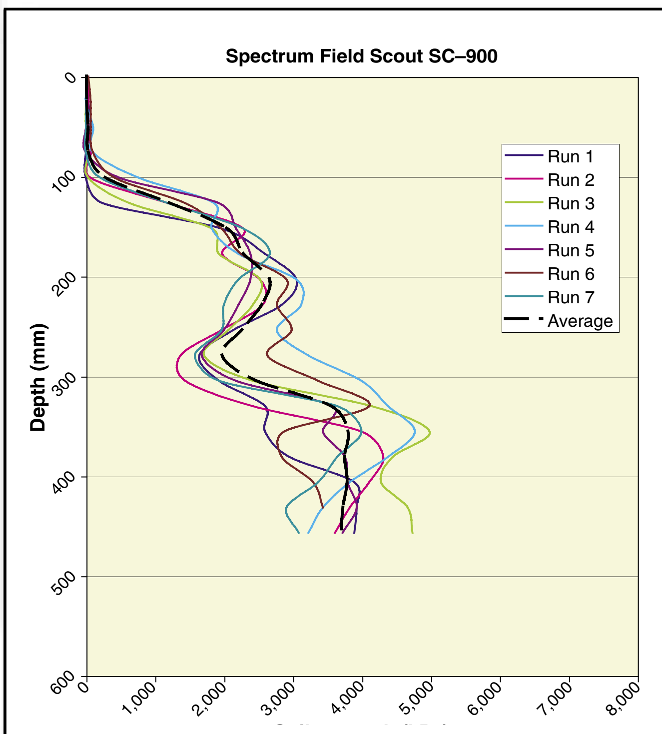


Figure 8—Repetition testing of the Spectrum Field Scout SC–900. The SC–900 outputs English or metric units.

Side-by-Side Comparison Tests

In this test, several flags were set in a line about 3 m apart at the Coeur d'Alene Nursery. One probe insertion was made within 300 mm of every flag using each instrument. Figures 9 and 10 show the results of two side-by-side comparisons. At each location, the overall trend in soil strength is consistent among the penetrometers. The Eijkelkamp Penetrologger appears to record slightly higher soil strengths than the other two instruments.

Because of its rocky compacted soils, the Coeur d'Alene Nursery was not the best testing ground for studying the consistency of penetrometer readings. It was a good testing ground to show typical conditions and difficulties that can be encountered in field conditions. Figure 11 shows that at a depth of about 350 mm the Eijkelkamp Penetrologger recorded higher soil strength than the graph can display. Typically, such readings occur when the probe hits a rock. Some areas of the nursery were so dry and compacted that the probe couldn't even be inserted into the ground.

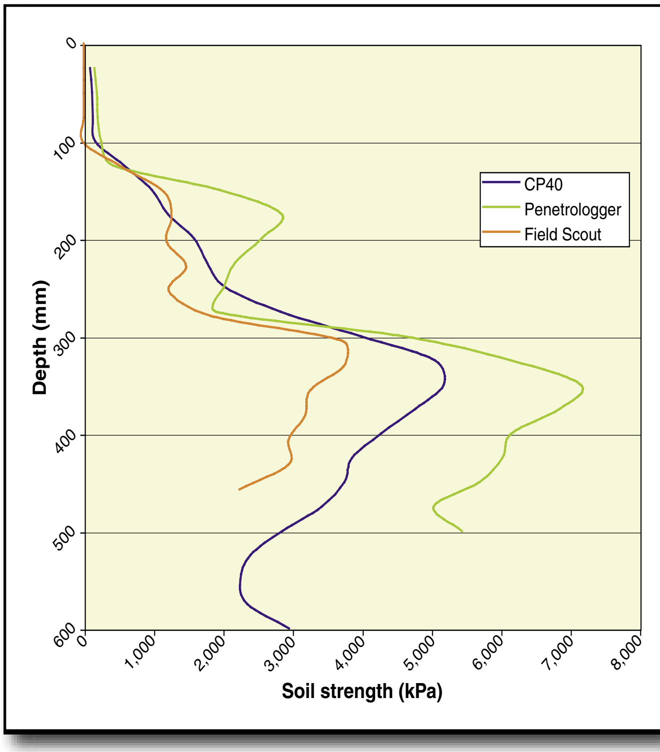


Figure 10—The results from this comparison test show less consistency, probably because of variation in ground conditions, equipment tracks, or operator inconsistency.

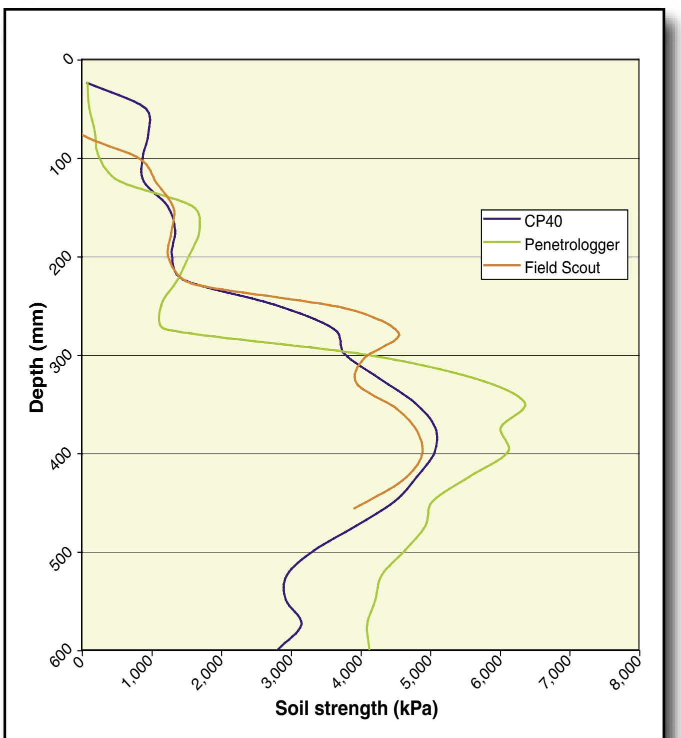


Figure 9—In the side-by-side comparison test, all three penetrometers were reasonably consistent. Probes were about 300 mm from each other.

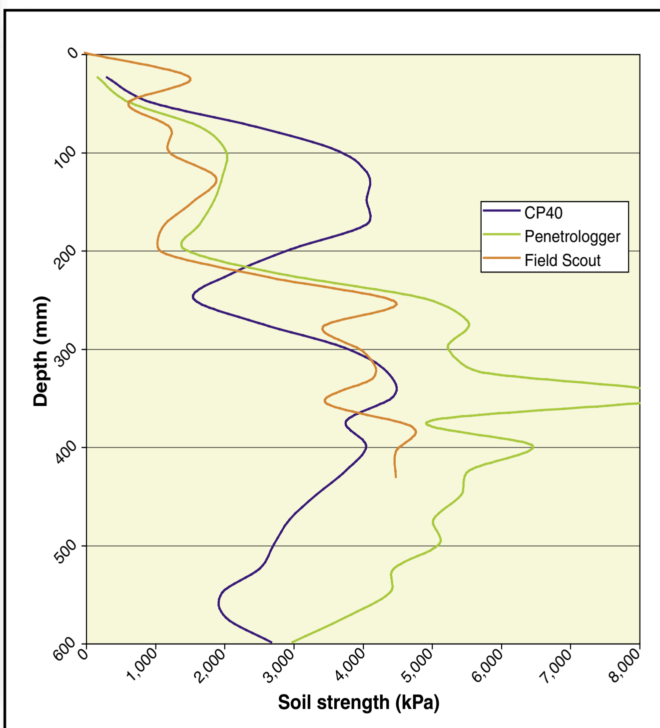


Figure 11—This test shows some variation between the three units in the side-by-side test. The wild jump in soil strength on the Eijkelkamp Penetrologger was caused by a rock or very hard object at a depth of about 350 mm.

Other Equipment Options

Other hand-held equipment that has been studied or is in use today includes two mechanical penetrometers: the Compact-O-Gauge and the dynamic cone penetrometer. A prototype of the Compact-O-Gauge was invented in 1991 by Greg Ruark, when he was a Forest Service researcher in North Carolina. The device simulates an acceptable vehicle pressure or load (as defined by contracts or other specification). The device works well, but only when assessing the top 200 mm of soil. In a recent conversation, Greg Ruark thought the hand-held electronic cone penetrometer could perform the same function as the Compact-O-Gauge but at greater soil depths.

The dynamic cone penetrometer uses a slide hammer dropped from a specific height to force a cone into the soil (figure 12). The recorded depth of penetration, weight of the slide hammer, and drop height are used to calculate the soil penetration resistance. Even though the two instruments function differently, MTDC conducted a quick side-by-side test of the dynamic cone penetrometer and the GP40 electronic penetrometer. Figure 13 shows the results. It takes about 5 min to collect data for one 500-mm probe with the dynamic cone penetrometer, compared to about 17 s with the electronic penetrometer. Dynamic cone penetrometers range cost from $1,200 to $2,500, depending on options and accessories.

Some other untested instruments include the Clegg Impact Soil Tester, Humboldt GeoGauge, and the nuclear density meter. Generally, these instruments just look at the top 100 to 200 mm of soil.

Figure 12—The slide hammer on a dynamic cone penetrometer is dropped from a given height for a given number of times and the probe's depth is recorded. This device is less expensive ($1,200 to $2,500) than the hand-held electronic cone penetrometers, but it takes much longer to use in the field and the cone index must be calculated after use.

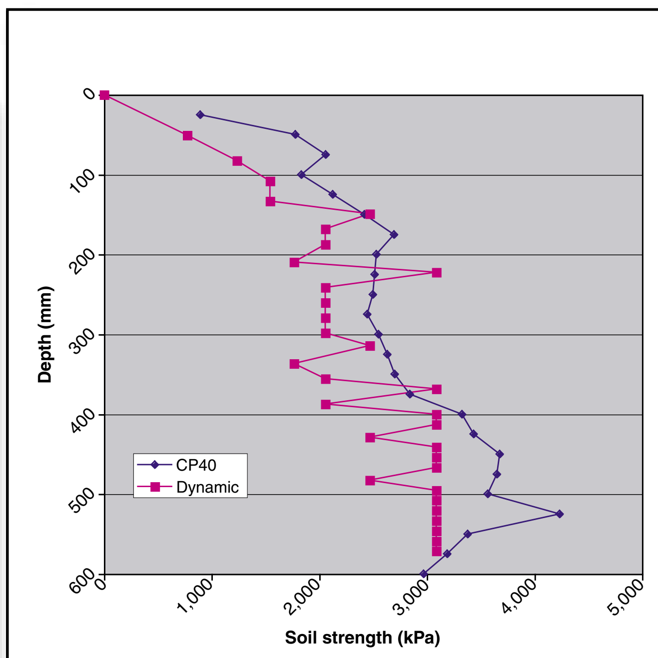


Figure 13—Relative differences between a hand-held electronic cone penetrometer and a dynamic cone penetrometer.

Discussions and Observations

A penetrometer's measurement of soil strength is very sensitive to soil compaction. However, using strength data for definitive interpretations of soil compaction requires correlations to other standard compaction tests or additional knowledge of soil moisture and soil characteristics. The hand-held electronic cone penetrometer can help pinpoint compaction problems that might require more extensive soil testing. It's also useful for looking at variability or changes in soil strength caused by equipment, vehicles, and foot traffic. Researchers are evaluating ways to use hand-held electronic cone penetrometers to help predict the likelihood of serious compaction in susceptible areas.

Reliable data requires penetrometer operators to insert the probe into the ground at a consistent speed. Certain soil or sampling conditions can greatly alter penetrometer readings and make them much less useful. An operator's field notes are helpful when data require editing because of unusual conditions, such as very rocky soils, large roots, hardpans or plowpans, voids such as gopher holes or large root channels, buried organic materials, and very dry conditions. The repetition tests conducted during this evaluation verify the need to probe several locations in a given area to better understand variations in soil conditions and operator inconsistency.

Vegetation growing near the soil surface can interfere with the hand-held electronic cone penetrometers, causing false depth readings. The Spectrum Field Scout SC–900 reported errors, rejecting the file, when weeds, sticks, or grasses were near the testing area. MTDC fabricated a ground target (a piece of U-shaped metal), similar to the one provided by Eijkelkamp and Agridry, to help reduce the error messages on the Spectrum Field Scout SC–900.

The graphic readouts on the Eijkelkamp Penetrologger and the Rimik CP40 are useful in the field. Both penetrometers give an indication of the insertion speed so the operator can speed up or slow down as necessary. If the penetrometer is not inserted at the proper speed, the operator has the option to reject or keep a specific file. The Rimik CP40 can be programmed to a specific insertion speed, sounding an alarm or rejecting data (based on the operator's preference) if the speed is not correct.

The Spectrum Field Scout SC–900 stops taking readings and requires the operator to start over if the proper speed is not maintained. This feature is frustrating because many times operators can tell that they hit a void or rock and could note this in a logbook. In tough conditions, it can be very frustrating to get one complete full depth reading with the Spectrum Field Scout SC–900.

The probe on the Eijkelkamp Penetrologger was longer and thinner than the probes on the other two units. This variation allows for deeper depth recordings, but the probe tends to bow in hard soils. Eijkelkamp offers a thicker rod, but it requires using a larger diameter cone that is more difficult to insert into compacted soils. In sandy or less compacted soils, the larger cone provides a broader range of testing capabilities.

Eijkelkamp recommends that the operator program a field plan with plot names, the number of measurements per plot, and the penetrometer parameters before taking readings. This programming is best done in the office using a computer, but can also be done in the field using the Eijkelkamp Penetrometer's touch screen. The Rimik CP40 and the Spectrum Field Scout SC–900 simply assign a file number as each probe insertion is completed.

Downloading information from the penetrometers to a computer is reasonably easy for all three penetrometers. Importing the information into spreadsheets is more difficult. The data from the Spectrum Field Scout SC–900 can be downloaded as well-formatted text files that need very little manipulation. Data from the Eijkelkamp Penetrologger and the Rimik CP40 require more manipulation when they are imported into a spreadsheet. We had to download each file individually from the Rimik CP40 because information could not be separated easily when more than one file was downloaded at a time.

The Rimik CP40 and Spectrum Field Scout SC–900 are designed to record location data from an external GPS receiver (not provided) at each probe location. The Eijkelkamp Penetrologger has no provisions for GPS. Because only two units had GPS capabilities, the GPS option was not tested by MTDC.

Recommendations

The Rimik CP40 seems to be the most practical hand-held electronic cone penetrometer of the three tested. It has the most data storage, provides a comfortable operating height, and performed well in the repeatability testing. The newest version is called the Rimik CP40II. The manufacturer says that the software for data manipulation has been improved. The updated model costs $5,100, about as much as the $5,200 Eijkelkamp Penetrologger.

If budget is the deciding factor, the Spectrum Field Scout SC–900 provides accurate data and costs just $1,495. Expect to spend a lot longer in the field trying to collect information because of the Spectrum Field Scout SC–900's rejection of all data whenever the probe is inserted too quickly or too slowly.

Penetrometer Contact Information

Model: CP40 and CP40II
Manufacturer: Agridry Rimik PTY LTD
Sales Representative: Soil Measurements System
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Manufacturer: Spectrum Technologies, Inc.
Sales Representative: Spectrum Technologies, Inc.
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Fax: 815–436–4460
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Web site: *http://www.specmeters.com*

Model: Penetrologger
Manufacturer: Eijkelkamp Agrisearch Equipment
Sales Representative: Soilmoisture Equipment Co.
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Gary Kees is a project leader specializing in reforestation and nurseries, facilities, recreation, and GPS projects at MTDC. He received his bachelor's degree in mechanical engineering from the University of Idaho. Before coming to MTDC in 2002, Gary worked for the Monsanto Co. in Soda Springs, ID, as a mechanical/structural engineer and project manager.

Library Card

Kees, Gary. 2005. Hand-held electronic cone penetrometers for measuring soil strength. Tech. Rep. 0524–2837–MTDC. Missoula, MT: U.S. Department of Agriculture Forest Service, Missoula Technology and Development Center. 12 p.

Describes tests comparing three hand-held electronic cone penetrometers: the CP40 (Agridry Rimik PTY LTD, $5,100 for the newer CP40II), the Field Scout SC–900 (Spectrum Technologies, Inc., $1,495), and the Penetrologger (Eijkelkamp Agrisearch Equipment, $5,200). Cone penetrometers are used to measure soil strength, which can be a concern during forest management activities that require the use of heavy equipment. A traditional mechanical penetrometer requires two persons to operate. Dynamic cone penetrometers take about 5 minutes to probe 500 millimeters deep. Newer electronic cone penetrometers that can be operated by one person probe 500 millimeters deep in just 17 seconds. These penetrometers can locate areas with excess soil strength, but they do not provide definitive measurements of soil compaction. The CP40 appeared to be the most practical of the three penetrometers tested. It had the most storage for data, a comfortable operating height, and performed well in repeatability testing.

Keywords: comparisons, equipment, nurseries, reforestation, soil compaction, soil mechanics, soil physical properties, soil strength, soil testing

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