FINAL REPORT

MODIFICATION OF THE CLEGG HAMMER AS AN ALTERNATIVE TO NUCLEAR DENSITY GAUGE TO DETERMINE SOIL COMPACTION

for

U.S. ENVIRONMENTAL PROTECTION AGENCY

RADIATION PROTECTION DIVISION

Prepared by

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EXECUTIVE SUMMARY

Title	**Modification of the Clegg Hammer as an Alternative to Nuclear Density Gauge to Determine Soil Compaction**
Sponsoring Agency	**U.S. Environmental Protection Agency (US EPA)** Administrative Contract Service Center 1200 Pennsylvania Avenue, NW EPA Order No. 4W-1850-NANZ
Project Officer(s)	Sally Hamlin and Behram Shroff Radiation Protection Division, U.S. EPA
Contractor	Gas Technology Institute (GTI) 1700 S. Mt. Prospect Road Des Plaines, Illinois 60018
Investigators	Khalid Farrag, Ph.D., P.E. Gas Technology Institute Phone (847) 768-0803 Khalid.farrag@gastechnology.org
Report Period	Final Report September 2004 – December 2005
Objective	The objective of this project is to enhance and modify the Clegg-Hammer (Clegg Impact Soil Tester) device to gain acceptance as an alternative to the Nuclear Density Gauge in soil compaction control. This was achieved by initiating a jointly-funded program with the utilities industry, the device manufacturer, and the U.S. EPA to modify and optimize the device for soil compaction measurements in the field. The modifications of the device included physical modifications to reduce its weight and improve its mobility in the field and electronic modifications to provide moisture reading and develop data storage and downloading capabilities.

Conclusion	The modifications of the Clegg hammer device enhanced its capabilities to correlate to soil compaction parameters (i.e. soil density and moisture contents) in the field. The device measures the soil Impact Value (IV) which correlates to several soil physical properties such as soil relative compaction and California Bearing Ratio (CBR). The device uses a non-nuclear soil moisture sensor type 'HydroSense SC620', manufactured by Campbell Scientific Inc., and stores the moisture content readings in the data file. The modifications of the device included: 1. Redesign of guide tube. This allowed for easier transport and mobility and eliminated the possibility of the hammer being removed from the guide tube. 2. Improved cable connection from hammer to readout box. 3. Ability to store the measurements and easily download the data to a personal computer. 4. Change user interface to include data entry and location information using an add-on GPS system. 5. Moisture measurement capabilities using add-on moisture probe for proper moisture monitoring prior to backfilling. 6. Handle extension for use in small keyhole excavations. 7. Carrying case and cart to facilitate device transportation in the field. Correlations were performed with typical soil types in the lab and the relationship between the device Impact Value (IV) and soil density were determined for these soils. The coefficients of the moisture sensor were also evaluated and stored in the readout box for direct display of soil moisture. The user can use these coefficients when compacting similar soils. Lab calibration is needed if the backfill is different than the soils used in the testing program.

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BACKGROUND

The Nuclear Density Gauge (NDG) is the current standard device for the quality control (Q/C) of soil compaction in road construction. The gauge operates by producing small doses of backscattered gamma waves. The radiation reflected from the soil is detected at the base of the gauge and converted to soil density when the gauge is calibrated to the specific soil. The gauge also has a neutron source to determine the moisture content by detecting the hydrogen in a soil sphere around the gauge (Figure 1). The specifications for the calibration and use of the gauge for moisture and density measurements of soil and asphalt surfaces are listed in several ASTM standard procedures [*1-3*].

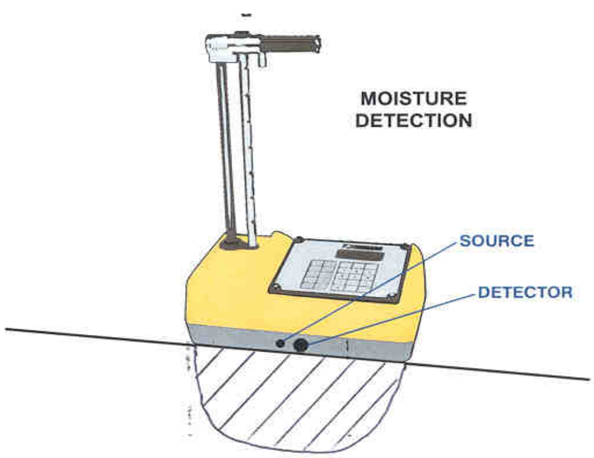

Figure 1 – Moisture detection using the NDG

The use of the NDG requires training and operation by a licensed technician and it is governed by regulations for its storage, transmission, and disposal. These requirements do not make the gauge a practical tool for user in repair jobs done routinely by the utilities in urban areas.

Furthermore, NDG gauges are operated in very mobile conditions in the field and the potential loss or damage to the gauges may result in harmful radiation exposure to the public.

These reasons have prompted a partnership between the Environmental Protection Agency (US EPA) and Gas Technology Institute (GTI) to search for other alternatives to monitor compaction performance and replace the NDG in roadway construction during utility installations and repair. These efforts have results in a multi-phase project jointly funded by EPA and the utility companies.

The first phase of the project included a comprehensive experimental program to evaluate several devices currently available in the market and correlate their readings to soil compaction and moisture conditions. These devices were the Utility Dynamic Cone, the Soil Compaction Supervisor (SCS), the Humboldt Geogauge, the 10-Kg and 20-Kg Clegg Hammers, the Army-Corps Dynamic Cone Penetrometer (DCP), the Panda device, and the NDG. The research program was completed in 2004 and the results are presented in GTI report number GRI-04/0067 [*4*]. The results demonstrated the applicability of some of these devices in the Q/C of soil compaction of trenches and utility cuts in roads and highways. The three highest-ranking devices were recommended for further modifications and improvements. These devices are the 10-Kg Clegg Hammer, the Utility Dynamic Cone, and the SCS.

The second phase of the research program consisted of implementing the recommended modifications in order to gain acceptance of the devices by the utilities and regulators in the Q/C of soil compaction. These modifications aimed at improving their operation, adding moisture measuring capabilities, data storage and display, and improving their field durability.

The EPA, Radiation Protection Division, joined with the utilities in the second phase in funding the modifications of the 10-Kg Clegg Hammer. This report presents the results of the modification program of this device.

DESCRIPTION OF THE CLEGG HAMMER

The Clegg Hammer (also called the Clegg Impact Soil Tester) consists of a compaction hammer operating within a vertical guide tube. When the hammer strikes the soil surface, a precision accelerometer mounted on the hammer feeds its output to a digital readout unit. The unit registers the deceleration in units of Impact Value (IV). The IV relates to soil strength and correlates with California Bearing Ratio (CBR) values. An ASTM standard covers the determination of the Impact Value (IV) of the soil [*5*].

A view of the Clegg Hammer used in the testing program of Phase-One of the research program is shown in Figure 2.

The first version of the Clegg Hammer was developed by Dr. Baden Clegg in Australia and was named 'The Clegg Impact Soil Tester' (Figure 3). It was first introduced at the 8th Australian Road Research Conference in 1976 [*6*]. Since then, it has been widely used in Australia and Europe. It is currently manufactured in the United States (Table 1) and is being used by consultants and contractors in several compaction control applications and particularly in the compaction testing of sports fields.

Figure 2 - The 10-Kg Clegg Hammer used in Phase-One of the study

Figure 3 – Early version of the Impact Soil Tester Device

Table 1 –The US Manufacturer of the Clegg Hammer

Clegg Hammer [10-kg & 20-kg Hammers]	Lafayette Instruments Company Contact Person: William (Ed) Jackson P.O. Box 5729 3700 Sagamore Parkway Lafayette, IN 47903 Phone: 765-423-1505 e-mail: ejackson@lafayetteinstruments.com

The device output, IV value, correlates to the soil CBR values by the relationship [*7*]:

$$CBR = [\ 0.24\ (IV) + 1\ ]^{2}$$

A correlation between the IV value and compressive strength of cement stabilized soil bases was also developed by the Portland Cement Association in the form [*8*]:

$$Log\ f''_C = 0.08087 + 1.3094\ Log\ (IV)$$

Where f''_C = cement stabilized soil compressive strength, psi

IV = Clegg Hammer Impact Value

The use of the Clegg Hammer in soil compaction measurements was evaluated in several studies [9-*12*]. A study by the New York State Electric and Gas Company (NYSEG) consisted of excavating twelve bellholes [*11*]. The bellholes were backfilled using three different soil types in three lifts per hole. The compaction effort was altered for each hole in order to ensure the achievement of acceptable and unacceptable backfill densities. Nuclear Density Gauge (NDG) readings and Clegg Impact Values (IV) were taken in order to determine the target IV values.

In another study [*12*], the correlation between the dry density and Impact Values were plotted for various ratios of number of passes per layer to the mean layer thickness. The study concluded that the IV value was potentially useful and convenient indicator of the degree of compaction for granular materials. On the other hand, the use of the Clegg Hammer to estimate dry density values required very carefully-determined calibrations for each material under consideration.

The previous studies also addressed the issue of whether the Clegg IV is a measure of the stiffness or strength of a compacted material. It was concluded that in weak or poorly compacted materials, the IV is most likely to be predominately a measure of strength due to the large penetration of the drop weight. On the other hand, with strong or well compacted materials, with small penetration in soil, the IV is most likely to be predominantly a measure of stiffness.

CORRELATION WITH SOIL COMPACTION

The Clegg Hammer is similar to many other soil compaction measuring devices in that it does not provide direct readout of soil density or soil moisture values like the NDG. It monitors soil strength-stiffness after the application of impact force on the soil. However, the output of the device provides a measure of soil densification and it can be successfully used when it is calibrated to compaction efforts and moisture conditions for various soil types.

A comprehensive experimental program was performed in Phase-One of the study to correlate the IV readings of the Clegg Hammer to soil compaction. The research program evaluated the device during the compaction of confined backfills in trenches and utility cuts in roads and highways (Figure 4). The backfills used in the tests were silty-clay soil, granular soil, and stone base material. The IV values were correlated to the density and moisture measurements from the NDG and the sand cone tests.

Table 2 shows the compaction properties of the backfills based on the AASHTO Standard T-180 for modified proctor tests.

The soils were placed and compacted at various layer thicknesses, dry densities, and moisture contents and measurements were taken at various levels of compaction efforts. The sand and stone were compacted using a vibrating plate and the silty-clay soil was compacted using a rammer compactor. Further detailed of the testing program and correlation results are in reference [*4*].

Figure 4 – Use of the Clegg Hammer and NDG in utility trench

Table 2 – Compaction Properties of Soils in Phase-One of the Testing Program

Soil Type	Maximum Dry Density (pcf)	Optimum Moisture Content (%)
Sand-SW1	119	5
Sand-SP2	102	11.5
Silty-Clay	123.7	11
Stone Base-CA2	142.9	7.8

1 pcf = 16.02 kg/m^3

The relationship between the 10-Kg Clegg 'IV' values and relative compactions of sand and silty-clay soils are shown in Figures 5 and 6, respectively. The figures show the correlations when the backfills are compacted at the optimum moisture contents of the soils. The results of the correlations for various backfills are shown in Table 3. The values in the table can be used to determine the compaction pass/fail criteria based on the IV results. It should be noted that these results were obtained for the specific soils used in the calibration program (*4*) and other soils used in the field may require performing similar calibration tests on the device.

The correlations between the Clegg values and soil moisture contents at constant density are harder to obtain (Figures 7 and 8). This is manly due to the difficulty of obtaining constant soil relative compaction for all the samples in the graph. The figures show that Clegg IV values slightly increase with the increase in the moisture content up to a maximum value and then decreased at higher moisture contents. The maximum moisture content values did not necessarily equal the optimum moisture values obtained from Modified Proctor tests.

Table 3 – Clegg Hammer IV values corresponding to 90% Relative Compaction [at optimum moisture content] for various soil types

	Sand	Silty-clay	Stone-base
10-Kg Hammer (IV)	6-8	8-12	12-14

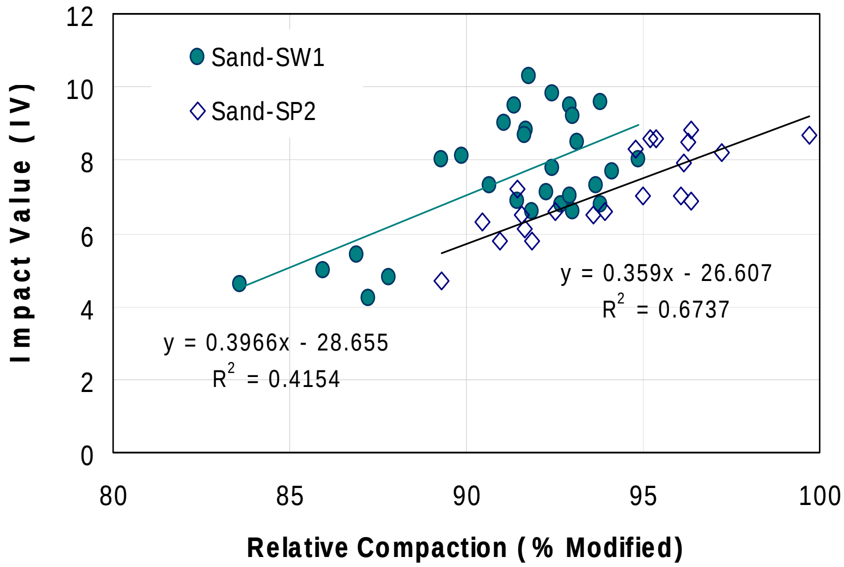

Figure 5 –The 10-Kg Clegg Hammer (IV) vs. relative compaction in sand

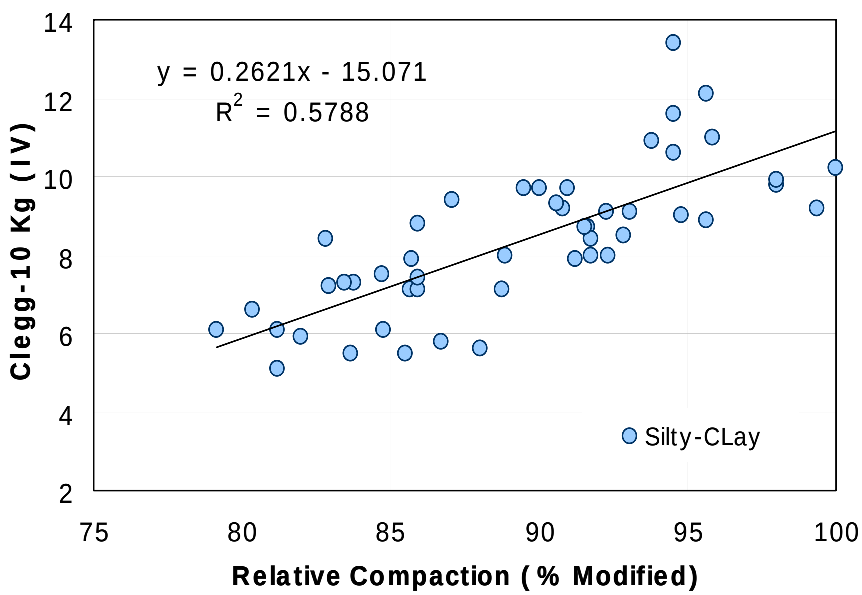

Figure 6 –The 10-Kg Clegg Hammer (IV) vs. relative compaction in silty-clay

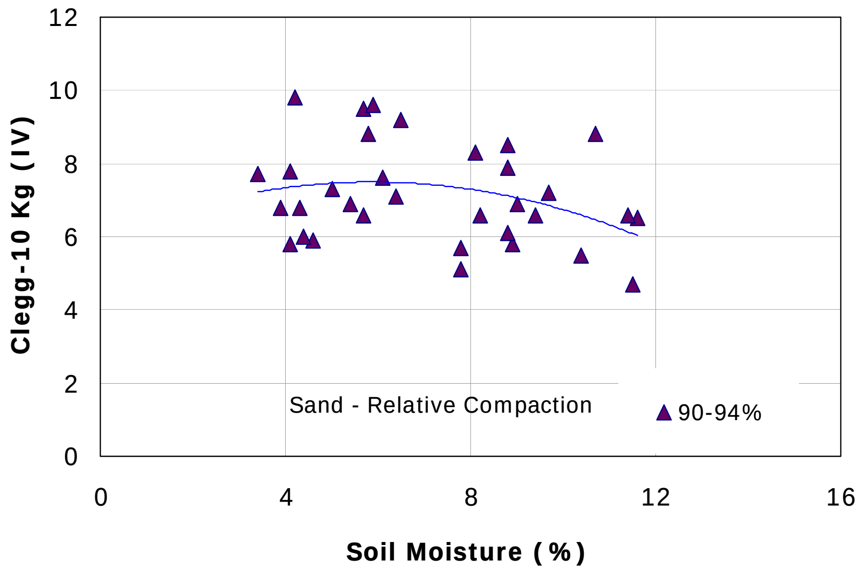

Figure 7 – Effect of change in moisture content on the IV results in sand

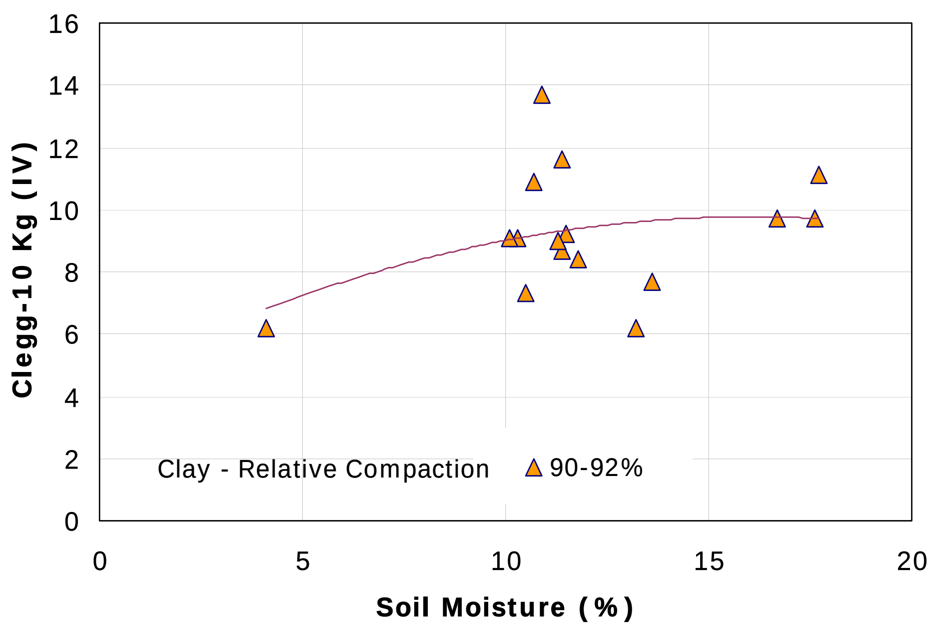

Figure 8 – Effect of change in moisture content on the IV results in clay

MODIFICATION OF THE DEVICE

The objectives of the device modifications were to produce a lighter weight and easier to operate model with data storage capabilities. The device modifications consisted of the following:

1. Redesign of guide tube. This allowed for easier transport and mobility and eliminated the possibility of the hammer being removed from the guide tube.
2. Improved cable connection from hammer to readout box.
3. Ability to store the measurements and easily download.
4. Change user interface to include data entry and location information.
5. Add-on moisture measurement for proper moisture levels prior to backfilling.
6. Handle extension for use in keyhole excavations.
7. Carrying case and cart to facilitate device transportation in the field.

The details of these modifications are as follows:

Modification 1

Redesign of the guide tube – This modification allowed for easier transport and mobility and substantially reduced the overall weight. The redesign eliminated the possibility of the hammer being removed from the guide tube and provided stops to control the drop height. The first prototype of the device with this modification is shown in Figure 9. The manufacturer redesigned this prototype to improve hammer drop, reduce weight of unit, improve manufacturability, and reduce manufacturing cost. The final design of the device is shown in Figure 10.

Modification 2

Improve cable connection from hammer to readout box - Several durable cables were evaluated. A right-angle quick connect was manufactured resulting in reducing the strain on the cable connection, more cable flexibility, and strength (figure 10).

Figure 9 – First prototype of the modified device

Figure 10- Final prototype with improved hammer drop and reduced weight

Modification 3

Ability to store the measurements and easily download data – This modification provided the ability to record and store of the compaction activities and protect the data from manipulation. The modifications included the development of a new readout box with a user interface capabilities to enable the selection of soil type, measurement of the soil moisture, measurement of the impact value, location in latitude and longitude, and time of measurement. Figure 11 shows the data interface screens in the readout box.

Figure 11 – View of the readout box

Modification 4

Easy user interface for location information – A simple GPS module with time and date stamp has been integrated into the readout box. The GPS module is offered as an option to the device and it is not provided with the basic Clegg.

Modification 5

Add-on soil moisture measurement – This option allows for the soil to be checked for proper moisture levels prior to backfilling. The moisture probe is an external sensor manufactured by Campbell Scientific Model HydroSense SC620 (Figure 12). The readout box has an input connector (Figure 13) for the moisture probe and it reads and stores the moisture reading when prompted by the operator. The HydroSense has been previously used and calibrated for soil moisture measurements at GTI.

The Campbell HydroSense SC620 is non-nuclear and it operates by measuring the changes in the soil dielectric constant due to changing water content. The specifications of the sensor are shown in Appendix B. Since the measurements of the sensor are affected by the soil electrical conductivity, a calibration of the meter with several soil types is required.

Figure 12 –Campbell moisture sensor (CS620) connected to the readout box

Figure 13 – The moisture sensor (CS620) connection to the readout box

Modification 6

Handle extension for use in small-hole excavations - A removable 6' strap is provided to extend the length of the hammer's handle. The strap allows dropping the device inside small-hole excavations. A 6 ft extension cable is also provided for the connection between the control unit and hammer.

Modification 7

Carrying case and cart (Figure 14) – The carrying cart facilitates the transport of the device to various locations on the job site. The cart is offered as an option and is not provided with the basic Clegg.

Figure 14 – The carrying cart for the Clegg hammer

EVALUATION OF THE MODIFIED DEVICE

The modified Clegg device was evaluated in two types of soils, namely granular soil with less than 5 percent silt and clay and silty-clay soil with about 60 percent passing sieve No. 200. Figure 15 shows the grain size distribution of the soil.

The soils were compacted in 8-inch thick lifts in a test section to about 90 percent relative compaction near their optimum moisture contents. The moisture content was measured using oven-dry samples in the lab and the Campbell HydroSense.

The Clegg device was used after the compaction of each layer (Figure 16). Site information, soil properties, and target impact value were stored in the box before testing. Date and time of the test are automatically stored in the data file.

TO run the device, the user selects between two test options. The first one is the "Basic" mode and it displays the impact value after each drop of the hammer. No storage capability is available in this mode. The second option is the "Advanced" mode. In this mode, the user records and stores site information, GPS data, and moisture data when the moisture probe is connected to the box. The "Advanced" mode was used in the testing program.

Figure 17 shows the selection screen in the readout box. The selection screen also includes a "View Data" option to view the data stored in the readout box and a "Download" option to down load the data stored in the readout box into a computer and a "Display" option.

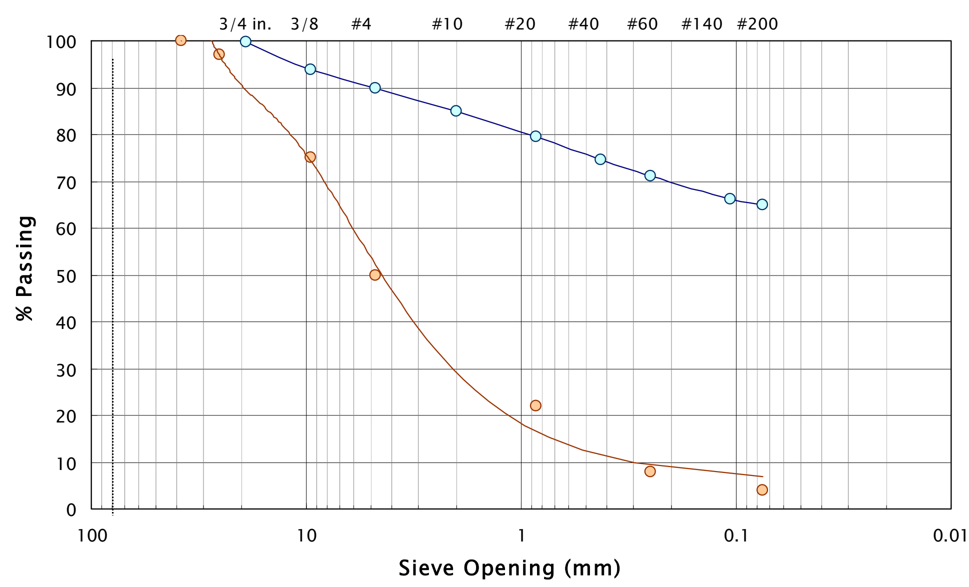

Figure 15 – Grain sized distribution of the soils in the testing program

Figure 16 – View of the device and the readout box in the test section

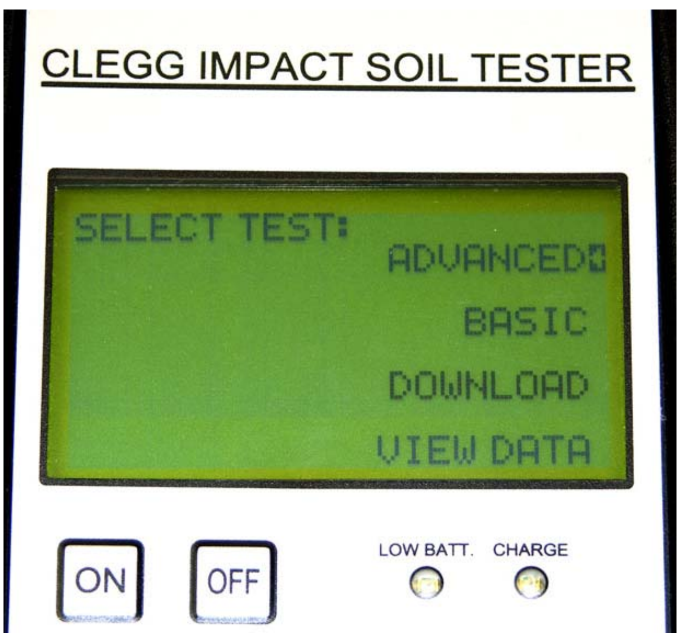

Figure 17 – The selection screen in the readout box

The test is performed by dropping the hammer four times on the soil layer. The "Advance' mode displays the Impact Value after each of the four hammer drops and registers the highest reading of the four drops as the test result. Figure 18 shows the display in the readout box during the test.

Data is transferred from the readout box to a personal computer through the USB connection cable. A utility-software is provided with the device to manage data transfer. Data is transmitted when the user clicks on the 'Retrieve Results' button in the main menu of the software (Figure 19). Figure 20 shows 'Data Retrieval' screen in the software for file format and location and Figure 21 shows an example of the output file in MS-Excel format.

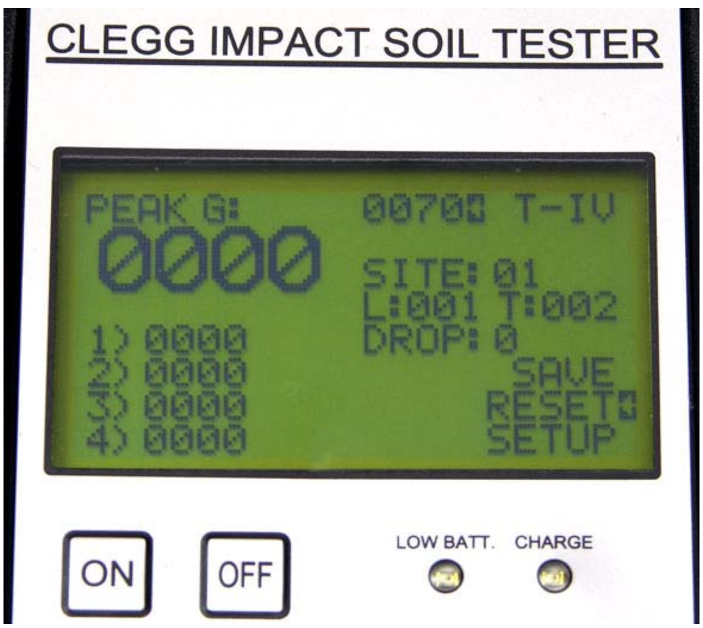

Figure 18 – Screen display of the readout box during testing

Figure 19 - The main menu of the utility software

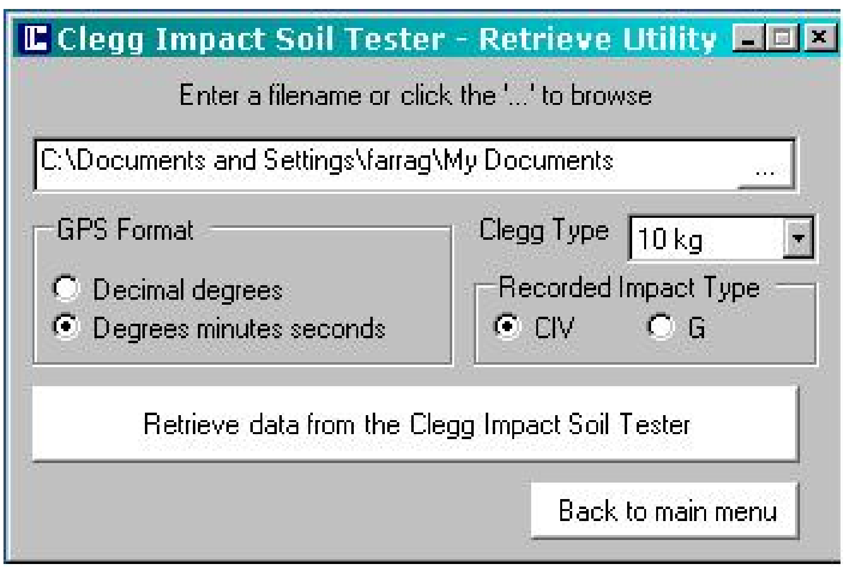

Figure 20 – Data retrieval options in the utility software

Clegg Impact Soil Tester stored data				Retrieved: 8/15/2005						
Site #	Layer #	Trial #	Time	Day	GPS	Recorded CIV	Target CIV	Recorded volumetric Moisture	Nominal volumetric Moisture	Soil Type
1	1	1	11:20	8/15/2005	N/A	14.1	12	11%	8%	GTI SOIL A
1	1	2	11:21	8/15/2005	N/A	7.5	12	11%	8%	GTI SOIL A
1	2	1	11:21	8/15/2005	N/A	13.7	12	11%	8%	GTI SOIL A

Figure 21 – Example of the output data file

The results of the impact values at various soil relative compactions are shown in Figure 22 for the granular soil compacted near its optimum moisture content of 11 percent. The results show a linear correlation with soil relative compaction. Soil relative compaction was determined from soil density measurements by the nuclear density gauge. Soil moisture content affects the IV values. The results of compaction tests at moisture contents of 12% and 16% are shown in Figure 23. The results show a significant reduction of the soil IV values with the increase of soil moisture content.

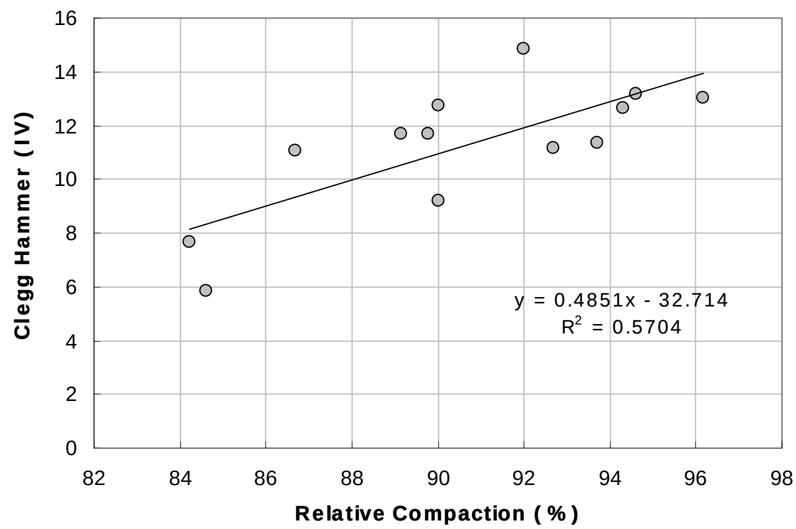

Figure 22 – Change of Soil IV values with relative compaction

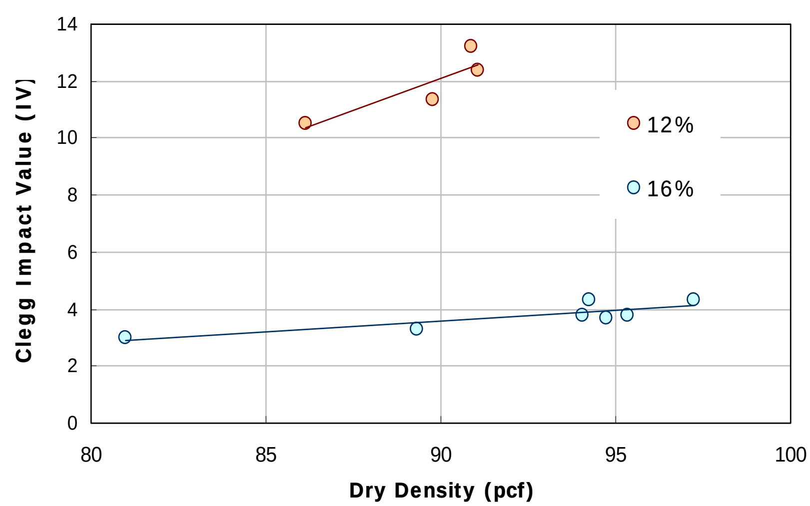

Figure 23 – Effect of soil moisture content on IV values

Calibration of the 'HydroSense' Moisture Sensor

The moisture sensor for use with the Clegg is water content reflectometer type 'HydroSense CS620' manufactured by Campbell Scientific. It is designed to measure volumetric water content of soil based on the measurements of its dielectric constant. The readout box of the Clegg has an input connector for the sensor and it reads and stores the water content based on the calibration coefficients of the sensor.

The probe rods of the sensor (see Figure *12*) are fully inserted into the soil at any orientation to the surface. The sensitivity of the measurements is greatest in the regions closest to the rod surface and air voids around the rods will reduce the measurement accuracy. The user manual [*13*] presents further details on the operation and calibration of the sensor.

The sensor should be calibrated in soils with known water contents prior to its use in the field to provide the calibration coefficients used in calculating the volumetric water content. The manufacturer provides standard calibration coefficients for standard soils (i.e. with bulk electrical conductivity less than 0.5 dS/m, bulk density less than 100 pcf, and clay content less than 30%) [*13*]. The following equations show the standard calibration coefficients for 12-cm and 20-cm long sensor rods.

$$\theta = 1.35\tau^2 - 0.932\tau - 0.08 \quad \textit{for 12-cm rods}$$

$$\theta = 0.481\tau^2 + 0.084\tau - 0.364 \quad \textit{for 20-cm rods}$$

Where, θ is the volumetric water content and τ *is the probe output reading.*

These factors are stored in the readout box for use with standard soils (Figure 24). These calibration coefficients are loaded in the readout box using the 'Transmit Setting' command in the main menu of the utility software (see Figure 19).

As mentioned earlier, calibration tests should be performed for other soils used in the field since the amount of clay and organic matters in a soil affect the dielectric measurements of water content. The sensor measures volumetric water content θ. Gravimetric water content ω can be obtained from the relationship:

$$\omega = \theta * \rho_{water} / \rho_{soil}$$

Where ρ_{water} and ρ_{soil} are the water and soil densities, respectively.

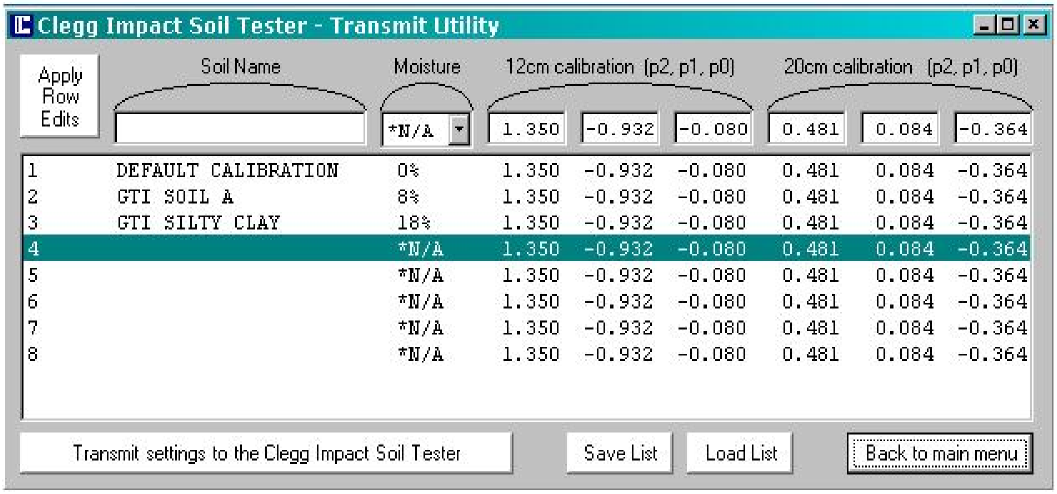

Figure 24– Calibration data of soil water content in the utility software

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APPENDIX A

DEVICE SPECIFICATIONS BROCHURE

(By Lafayette Instrument Company)

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CLEGG Impact Soil Tester

Lafayette Instrument

An universal instrument for the assessment of soil compaction, surface stiffness, and impact characteristics

Dynamic Test

The basic principle behind the Clegg Impact Soil Tester is to obtain a measurement of the deceleration of a free falling mass (hammer), from a set height, onto a surface under the device. The impact of the hammer produces an electrical pulse, which is converted into a Clegg Impact Value (CIV). Four successive blows of the hammer on the same spot constitutes one test with the peak CIV output to the digital display. The CIV is displayed in units of tens of gravities.

**Reference ASTM test methods D5874 and F1702.*

10kg Clegg

cart is optional

Durability

The Clegg is constructed to be extremely durable and easy to operate. The hammer and guide tube are constructed from steel and aluminum, and will give you years of reliable, accurate service.

Versatility

The Clegg may be transported and operated by one person. The Clegg offers the convenience of rapidly scanning compaction variation over large areas. In research studies, 200 tests were performed with the Clegg in a half-day.

The Clegg can test a full range of soils and soft rocks as encountered in the construction of flexible pavement and earthworks. It is useful for quickly checking variations during construction and monitoring changes over time due to seasonal environmental changes or road traffic as well as testing natural and "as constructed" conditions.

Data Collection

The handheld Control Unit is a microprocessor driven device and is powered by rechargeable batteries with an integrated battery charger circuit.

The user can choose from several data and test options by using a simple menu routine and the three buttons on the handheld unit. The BASIC option allows the user to simulate the exact function of the original Clegg Control Unit. The ADVANCED option enables the user to store Impact Values, Moisture Data (directly from a moisture probe), Test Site information, Time & Date, and Global Positioning information (optional accessory). The handheld unit can store up to 864 impact values over 72 test sites.

The handheld control unit has a USB port that allows information to be shared between a computer and the handheld unit. This is accomplished through the Transmit and Retrieve Utilities contained in the Clegg software CD.

Through the Transmit Utility, the user may download data to the handheld control unit. This includes information on Soil Types, Target Impact Values, Target Moisture Values, and moisture probe calibration constants.

Through the Retrieve Utility, the user can download information from the handheld unit. This includes Impact Readings and associated data such as Time & Date, Moisture Readings, Test Site and GPS information to the computer.

Simple and Quick Test Procedure

The test procedure is very rapid and can easily be performed by site personnel with minimal training. Each test can be completed in less than 30 seconds. The results are immediate.

1. Select a level surface.
2. The guide tube is set into position.
3. Using the display menu, the test site/location is selected and the control is set for the test option. (Also at this step, moisture and GPS information can be recorded.)
4. The hammer is raised to the top of the guide tube and the hammer is released allowing it to fall freely and cleanly.
5. Without moving the guide tube, the hammer is raised and released three more times.
6. The operator selects the Save option on the display menu and the test result (Peak CIV) is stored in memory for that test site.
7. Move to next test site.

Literature Request & Ordering Information

If you wish to receive further information on the Clegg or to place an order, please contact:

Lafayette Instrument

3700 Sagamore Parkway North · P.O. Box 5729 · Lafayette, IN 47903 U.S.A.
Tel: (765) 423-1505 · Fax: (765) 423-4111 · Toll-free: (800) 428-7545
E-mail: clegg@lafayetteinstrument.com · www.lafayetteinstrument.com

APPENDIX B

MOISTURE SENSOR BROCHURE

(By Campbell Scientific, Inc.)

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HydroSense™

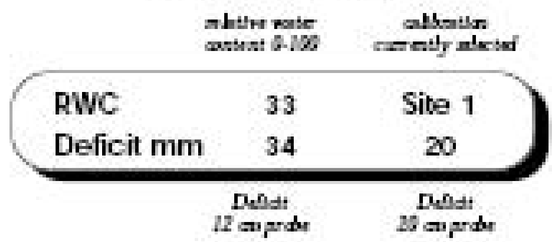
Soil Water Measurement System

The HydroSense System combines a compact, handheld display and a sophisticated soil water sensing probe in a portable package to provide quick and reliable soil water content measurements. Each measurement takes less than one second and is obtained by inserting the probe rods into the soil and pressing a single button on the display unit. A choice of 12- or 20-cm long probe rods makes HydroSense a versatile tool for monitoring and managing soil water in a wide range of conditions.

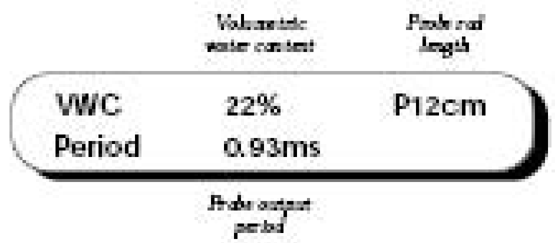
The microprocessor-controlled circuitry and two-line readout are contained in a splashproof enclosure that includes two integral membrane buttons used to operate the system. A 5-foot coiled cable connects the display to the probe. The 5 mm diameter stainless steel rods are an integral part of the electronic circuitry encapsulated in the epoxy probe head. The parallel rods constitute a driven transmission line which is sensitive to dielectric permittivity and consequently water content.

The HydroSense has two modes of operation. The water content measurement mode uses standard laboratory calibrations to provide percent volumetric water content in the range from air dry to saturated. In the water deficit mode, HydroSense measurements are taken at lower and upper water contents as specified by the user and stored in memory as reference values. The reference values are then applied to subsequent measurements to determine the amount of water that must be added to bring the soil to the upper water content.

Water Deficit Mode



Water Content Measurement Mode



Specifications

Model	**CD620 – HydroSense Display Unit**
Measurement Parameter:	Volumetric Water Content (%), Water Deficit (mm)
Housing:	Splash resistant
Display:	16-character, two line LCD display
Keypad:	Two-button membrane keypad
Power:	3 Vdc – 2 AAA alkaline batteries
Battery Life:	Approximately 12 months typical usage
Dimensions:	120 x 73 x 24 mm (4.7" x 2.9" x 0.9")
Weight:	160 grams (7 oz.) including batteries
Reading time:	<50 milliseconds

Model	**CS620 – Water Content Probe**
Accuracy:	±3% water content in materials with electrical conductivity < 2 dS m^{-1}
Resolution:	0.25%
Range:	Dry to saturation
Output:	Square wave pulse train with ±2.5 Vdc amplitude
Body Dimensions:	105 x 70 x 18 mm (4.1" x 2.8" x 0.7")
Rod Dimensions:	5 mm (0.2") diameter 32 mm (1.3") spacing 120 or 200 mm (4.7", 7.9") length
Cable:	Spiral cable, 200 cm (6.6 ft) extended
Weight:	390 grams (14 oz.)

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