



Humboldt GeoGauge®

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1.0: Introduction

1.1: GeoGauge® Benefits

The Humboldt GeoGauge® is a hand-portable instrument that provides a simple, rapid and precise means of measuring in-place two key engineering and mechanical properties of prepared soil and aggregate, lift stiffness and material modulus.

Compaction Quality Control (QC) of subgrades, bases and pavements based on modulus or stiffness, as enabled by the GeoGauge, will reduce compaction costs by 30% and roadway maintenance by at least 50%.

The GeoGauge, unlike density gauges, can measure in-place the load bearing characteristics of compacted materials. This enables real estimates of roadway performance and provides the basis for reducing construction margins, lower construction costs by at least 20%.

The GeoGauge can be used in-place to estimate CBR and Resilient Modulus or estimate the results of plate load tests, laboratory R-Value, FWD or DCP with more speed and simplicity and at a much lower cost.

The GeoGauge can be used to evaluate the material strength gained by stabilization of any kind very soon after installation, allowing construction to resume as soon as the material can support traffic loads while assuring ultimate material strength.

The GeoGauge can enable construction methods that reduce roadway maintenance by at least 50%.

- Asphalt & Concrete Pavement
- Full Depth Pavements
- Full Depth Roadway Reclamation
- Airport Runways & Infields
- Unpaved Roadways
- Structures Buried Under Roadways

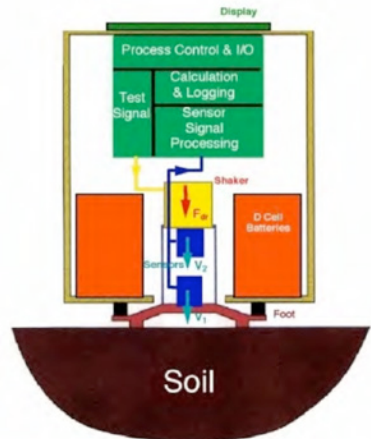
The GeoGauge can be used to simply and rapidly build the quantitative basis for implementing mechanistic-empirical roadway design by cataloging as-built resilient modulus in a fraction of the time required for laboratory measurements.

The GeoGauge is intended to meet a need that has existed since quality has been important to earthworks construction. This is the control of the construction process via the same physical parameters that earthworks are designed with. For example in highways:

- Lift Stiffness is used to assure the uniform & effective transfer of loads from the pavement to the base, subbase & subgrade below and
- Material Modulus is used to assure that each material allows the highway system to structurally perform as needed.

1.2: How The GeoGauge® Works

The GeoGauge measures a material's mechanical impedance at the surface of the ground. In other words, it measures the force imparted to the soil and the resulting surface deflection as a function of frequency. Stiffness, force over deflection, follows directly from the impedance. The GeoGauge imparts very small displacements to the ground ($< 1.27 \times 10^{-6}$ m or $< .00005$ ") at 25 steady state frequencies between 100 and 196 Hz. Stiffness is determined at each frequency and the average from 25 frequencies is displayed. The entire process takes about one minute. At these low frequencies, the impedance at the surface is stiffness controlled and is proportional to the shear modulus of the soil. With Poisson's ratio, shear and modulus can be derived.



**GeoGauge Schematic
Figure 2**

The GeoGauge weighs about 10 kg (~ 22 lb), is 28 cm (~ 11") in diameter, 25.4 cm (~ 10") tall and rests on the soil surface via a ring-shaped foot (Fig. 2). The foot bears directly on the ground without penetrating it and supports the weight of the GeoGauge via rubber isolators. Also attached to the foot are the shaker that drives the foot and sensors that measure the force and displacement-frequency history of the foot.

The GeoGauge is placed on the ground to make a measurement with little or no preparation of surface. Typically, a slight rotation of the GeoGauge is needed to obtain the desired 100% contact between foot and ground (Fig. 3). On particularly hard or rough surfaces, seating of the foot is assisted by the use of less than 10 mm (1/4") of moist/wet material such as mortar sand. Common field practice is as applicable to the GeoGauge as it is to most current field measurement of material performance. The detailed procedure for using the GeoGauge and preparing the ground is described later in this guide.



The GeoGauge displays and logs the data in memory with sufficient capacity for a full day of data gathering (100s of measurements). The data may be downloaded to a PC for archiving and further analysis. It is powered by 6 disposable and common D-cell batteries. Measurements can be performed as close to operating construction equipment as operator safety will allow.

Many current methods of measuring material modulus or lift stiffness in the field require large forces to produce a measurable deflection. The GeoGauge uses technology borrowed from the military to measure very small deflections, allowing much smaller loads. The GeoGauge does not measure the deflection resulting from the GeoGauge weight. Rather, the GeoGauge vibrates, producing small changes in force that produce small deflections. The material deflects an amount δ , which is proportional to the outside radius of the ring foot (R), the Young's modulus (E), the shear modulus (G) and Poisson's ratio (ν) of the soil¹. The stiffness is the ratio of the force to displacement: $K=P/\delta$. The GeoGauge produces soil stress and strain levels common for pavement, bedding and foundation applications (27.58 kPa or ~ 4 psi). Young's and shear modulus can be determined from GeoGauge measurements if a Poisson's ratio is assumed (Fig. 4).

GeoGauge measurements intentionally mimic Resilient Modulus measurements as much as typical site conditions will allow. This allows GeoGauge measurements to be related to Resilient Modulus.

1.3: GeoGauge® Applications

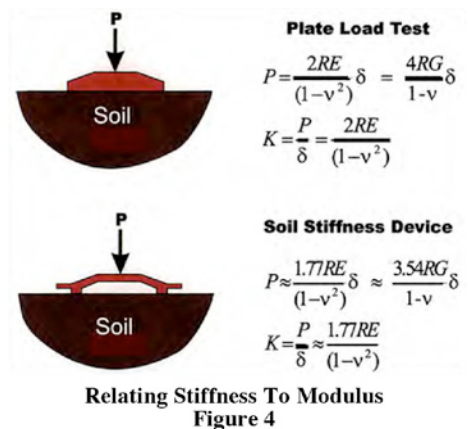
The GeoGauge has an application anywhere there is a need to structurally evaluate a construction material in-place. Following are some examples.

The GeoGauge is better suited for the in-place QC of unbound materials than any other available instrument for:

- In-place estimates of Resilient Modulus
- Modulus measurements that relate well to relative compaction
- Identifying structural anomalies
- Quantifying strength gain with time
- Obtaining precise measurements

This is based on the findings of the Transportation Research Board's National Cooperative Research Program Project 10-65.

The GeoGauge can be used in the QC of compacted subgrades and bases. The QC method utilizes a control strip and initially established target stiffness values that are related to conventional relative compaction. Ultimately, target stiffness values are related to design values and expected values based on experience (e.g., Resilient Modulus). Appendix 1 is a case study of such a QC method.



The GeoGauge can be used in the QC of stabilized materials. The QC method can determine how soon a material can bear construction loads, determine the ultimate strength from measurements at the time of installation or assure structural uniformity of the material. Appendix 2 is a case study of such a QC method on a cement treated bases. Appendix 3 is a case study of use on a lime treated subgrade.

The GeoGauge can be used in-place to estimate CBR and Resilient Modulus or estimate the results of plate load tests, laboratory R-Value, FWD or DCP with more speed and simplicity and at a much lower cost.^{2, 3 & 4}

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- 2 Development Of Models to Estimate The Subgrade And Subbase Layers Resilient Modulus From In-Situ Devices Test Results For Construction Control, 2005, Louay Mohammad, Ananda Herath and Ravindra Gudishala, Louisiana Transportation Research Center, Baton Rouge, LA 70808, FHWA/LA.05/406
 - 3 Assessment Of In-Situ Test Technology For Construction Control Of Base Courses And Embankments, 2004, Murad Y. Abu-Farsakh, Ph.D., P.E., Khalid Alshibli, Ph.D., P.E, Munir Nazzal, and Ekrem Seyman, Louisiana Transportation Research Center, Baton Rouge, LA 70808, FHWA/LA.04/385
 - 4 Field R-Value Correlation Method Development, 2006, Lary R . Lenke, Evan M. C. Kias, Richard Jenkins, Christopher Grgich, University of New Mexico Department of Civil Engineering, Albuquerque, NM 87131, NM04MSC-02.1

2.0: Button (KeyPad) Functions



ON

Turns on the gauge. When pushed, the GeoGauge goes through an electronics check, displays the present battery voltage and finally displays the value of the previous or last measurement made. The gauge is then ready to perform a new measurement.



OFF

Turns off the gauge.



SHIFT

To execute any of the four buttons with a blue background ("ERASE", "PRINT", "TEST", "UNIT"), you must first press the "SHIFT" button. After pressing "SHIFT", do not press the blue keys until "SHIFT" is displayed in the STIFFNESS window. Note: the "STOP" button does not require using "SHIFT".



ERASE

Erases all saved data. Starts measurement ID at "1"



SAVE

Saves the current measurement. This button must be pushed to save each measurement. If it is not pushed, the data for the last measurement will be discarded. Note: When the GeoGauge memory is empty, the first 20 measurements saved will contain the uniquely assigned measurement ID, measurement time and date, frequencies and the real and imaginary parts of the force and displacement (Research Format). There after, only the measurement ID, the displayed stiffness in SI units, and the time and date will be saved for the next 480 measurements. At this point the GeoGauge's memory is full and "db full" is displayed.



PRINT

Begins the downloading of data, via the IR COM port.



MODE

Shows the target stiffness value, only in SI units, in the ID/TARGET window and the ratio of the measured stiffness to the target stiffness in the STIFFNESS window. The target value can be incrementally changed in graduations of 0.5 MN/m by scrolling up or down using the "INCR" or "DECR" buttons respectively. Press "MODE" again to return to the previous display.



MEAS

Starts the actual stiffness measurement. The measurement will be completed in about 70 seconds. Pressing "SHIFT" and then "MEAS" will enter the Poisson's Ratio value display. Each successive pressing of the "SHIFT" and then "MEAS" buttons will enter the time/date display. Press "SAVE" to save the new entry.



START

Begins the viewing or scrolling through the saved measurement data. You need to press the "INCR" or "DECR" button to scroll up or down the measurement values along with the measurement ID. You cannot take a measurement while viewing memory. Exit this database mode status by pressing the "STOP" button.



STOP

Exits the viewing of the saved measurement data. Pressing it returns the gauge to normal mode. The "SHIFT" button is not used for this action.



TEST

System runs a self-test. Displays the electronic circuit board serial number, battery voltage, "batt", runs an internal electronic circuitry check, "SELF" "TEST" and then displays the results, "no" "ErrorS". The system runs the same test when the gauge is first turned on.



UNITS

Pressing "SHIFT" and then "UNITS" alternates between SI and English measurement units. Pressing just "UNITS" toggles between displaying stiffness and modulus.



INCR

With "START" scrolls through saved measurement data in order of increasing value, see "START" above.



DECR

With "START" scrolls through saved measurement data in order of decreasing value, see "START" above.

3.0: Technical Specifications

Conforms to ASTM D6758

Soil Measurement Range	From	To
<i>Stiffness</i>	MN/m (klbf/in) 3 (17)	MN/m (klbf/in) (399)
<i>Young's Modulus</i>	MPa (kpsi) 26.2 (3.8)	MPa (kpsi) 610 (89)

Measurement Precision (typ., Coefficient of Variation): < 10 %

Depth of Measurement (from surface): 220 to 310 mm (9 to 12 in.)

Calibration	Laboratory
Accuracy (% of actual mass)	< + 1%

Electrical

Power Source	(6) D size disposable cells
Battery Life	Sufficient for 500 to 1,500 measurements

Mechanical

External Materials	Aluminum case & foot, rubber isolators & seal
Vibration	<1.27 x 10 ⁻⁶ m (<0.0005 in.) @ 125 Hz
Level re Vertical	± 5 °
Operating Temperature	0°C to 38°C (ambient)
Storage Temperature	-20°C to 50°C
Humidity	98%, without condensation
Gauge Dimension	280 mm (11") Diameter, 255 mm (10") Height (without handle)
Weight	Net: 10 kg (22 lbs), Shipping: with case, 17.7 kg (39 lbs)

Standard Accessories

Transit Case, 6 'D' Batteries, User Guide

Optional Accessories

- Infrared (IR) serial interface adapter cable with software template (3.5" floppy, PC only)
- Verifier Mass

ALL TECHNICAL, PERFORMANCE AND OTHER SPECIFICATIONS ARE SUBJECT TO CHANGE.

4.0: Display Messages

- StiF** Announces the measured value of stiffness (MN/m), (displayed in ID window). The measured value of stiffness is displayed simultaneously in the STIFFNESS window.
- SENS OvLOAD** Indicates that the current measurement was aborted due to the sensors being overloaded. The word "SENS" is displayed in the ID/TARGET window and the word "OvLOAD" is displayed in the STIFFNESS window. This can be caused by a too soft material, a too stiff material or the foot being seated improperly. When displayed, the current measurement must be repeated.
- 5d** Announces the standard deviation of all 25 frequency dependent stiffness measurements relative to the measured (average) value of stiffness (displayed in ID/TARGET window) at the end of the current measurement. The standard deviation is displayed simultaneously in the STIFFNESS window.
- noiS** Indicates that the GeoGauge is measuring ambient noise (displayed in ID/TARGET window). The noise measurement takes about 10 seconds after depressing the MEAS button. Nothing is displayed simultaneously in the STIFFNESS window.
- dAtA** Indicates that the GeoGauge is taking stiffness data over 25 frequencies between 100 and 196 Hz (displayed in ID/TARGET window). This follows the noise measurement and takes about 55 seconds. Nothing is displayed simultaneously in the STIFFNESS window.
- Snr** Announces the display of the Signal Noise Ratio for the current measurement (displayed in ID/TARGET window) at the end of the current measurement. The Signal Noise Ratio, in dB, is displayed simultaneously in the STIFFNESS window.
- SI or Eg** This message indicates the ready mode and the stiffness units (displayed in ID/TARGET window). The GeoGauge is ready to take the next measurement. The Stiffness window shows the value of the last measurement, in SI units (MN/n) or English (Eg) units (klbf/in).
- ALrE StorEd** Indicates that the current measurement value has already been stored in the memory. The word "ALrE" is displayed in the ID/TARGET window and the word "StorEd" is displayed in the STIFFNESS window. If you don't know if the last measurement has been stored, the GeoGauge will tell you.

- OVFLO** Indicates that the database memory is full. No additional measurements may be taken. You need to download or erase before additional measurements are taken.
- 0.00** Indicates that the last measurement was not accepted due to one of two reasons. One, that the sensors overloaded due to softness or extreme hardness (too much movement). Two, that six or more of the 25 total frequencies were unacceptable from low Signal to Noise Ratio.
- db - on** Indicates that the View Memory data base mode has been entered. It is displayed momentarily in the STIFFNESS window. After this appears, pressing the INCR or DECR buttons will scroll through the stored data. Ordered pairs of measurement ID numbers and the measured values of stiffness will be displayed sequentially, in the order they were measured, in the ID/TARGET and STIFFNESS windows respectively.
- db - off** Indicated that the View Memory data base mode has been exited. It is displayed momentarily in the STIFFNESS window.
- StorEd** Announces that the current measurement has been stored (displayed in STIFFNESS window). The assigned measurement ID number is displayed simultaneously in the ID/TARGET window.
- bAtt** Announces the value of the combined voltage of the six (6) D-batteries (displayed in ID/TARGET window). The voltage is displayed simultaneously in the STIFFNESS window.
- SELF TEST** Indicates that the GeoGauge is going through a self test of its electronics. The word "SELF" is displayed in the ID/TARGET window and the word "TEST" is displayed in the STIFFNESS window.
- nO ErrOrS** Indicates that the results of the self test is within specified limits (displayed in ID/TARGET window).
- POI5** Indicates the Poisson's Ratio value being displayed. Scrollable from 0.20 to 0.70 in increments of 0.05. Pressing the save button after setting the Poisson's Ratio value will retain that value in memory for subsequent Young's modulus measurements
- 51-5** Stiffness in SI value, MN/m. (Mega Newton per meter)

51-Y

Young's modulus in SI value, MPa. (Mega Pascals)

Eg-5

Stiffness in English value, klb/in. (kilo pounds force per inch)

Eg-Y

Young's modulus in English value, ksi or kpsi (kips per square in.)

5.0: Get Acquainted With The GeoGauge®

Before using the GeoGauge to make measurements that matter, get acquainted with it. Get used to what it takes to make a precise measurement. Get acquainted with how the stiffness of prepared materials varies.

Select a site that is representative of the material you will be measuring. Bases or subbases with high aggregate contents should be avoided for awhile until the technician gains some experience.

Layout measurement locations in a straight line, with the increment between locations being about .6 meter (2 ft) or less. Walking over measurement locations will not disturb the surface and affect a measurement. The physical properties of prepared construction materials can be extremely variable. They can be much more variable than expected. Over a .6 meter (2 ft) increment, it is not uncommon for soil stiffness to vary more than 1 MN/m! So, the initial over-sampling of a material is desirable to develop accurate profiles. During the actual compaction, the engineer will specify the measurement interval. Intervals of 15 m (50 ft.) to 145 m (500 ft.) are typical for material quality control measurements.

The site and layout of measurement locations should allow for repeated measurements. Six (6) locations is a good number. Site conditions are continually changing, such as: varying moisture content, sandy soils drying out rapidly, and clays drying slowly. Making a comprehensive set of measurements rapidly assures material characterization under one set of conditions (e.g., with in ~ 1 hr. of compaction). Knowing site conditions is critical to characterizing a material.

Repeat measurements at each location at least three times. These repeated measurements will get you familiar with GeoGauge precision for the corresponding surface conditions. Seating the GeoGauge to the ground is the most important part of the measurement (see GeoGauge Seating below). Always remove the GeoGauge between measurements and do not touch the GeoGauge during a measurement. The number of repeated measurements depends on the site. Don't confuse the measurement precision (repeatability) with location-to-location variability in the material.

Perform GeoGauge measurements first, before other companion measurements. Performing measurements such as FWD or nuclear gauge measurements will disturb the material and affect any subsequent measurements.

Again, practice making measurements before performing the measurements that matter. Site conditions and the type of material will affect how you will want to place the GeoGauge on the surface. Knowing how to properly seat the GeoGauge's foot on the surface, as described below, and being consistent in how you use the GeoGauge is critical to good measurements.

Remember, compacted materials are not as structurally uniform as most people expect. Stiffness is a sensitive enough measurement of a material to reveal this

variability. Be prepared to question and understand what you are doing with all the measurements you make, not just the GeoGauge. Process control for material structures is new and will take different thinking to effectively implement it.

6.0: GeoGauge Seating

A good GeoGauge measurement arises from good seating, the foot to surface contact. It cannot be emphasized enough that preparing the soil surface is key to good seating. Merely having a level material surface is not enough, the foot must have sufficient direct contact with the soil. Experience shows that ~ 100% of the foot's surface in contact with the material surface is needed. If a measurement precision represented by a Coefficient of Variation of < 10 % is achieved from repeated measurements at a single location, then seating is sufficient.

On loose or soft materials, place the GeoGauge on the ground. Rotate the GeoGauge no more that 1/2 of a revolution by holding the side or bottom of the gauge. Now you can take the measurement

Lifting the gauge from the measured spot and observing the imprint made can readily judge the degree of foot contact. Occasionally, the material is hard and smooth enough or rough and irregular enough that the imprint made by the foot cannot be seen. This is where measurement precision will be the judge.

If the imprint made by the foot cannot be readily seen, the simple solution is to apply a thin patted layer of clean moist mortar sand per ASTM C144-02, about 5 to 10 mm thick (1/8 to 1/4 inches), on the spot to be measured. Level and pat down firmly with your hand to roughly 10 mm thick. Place the GeoGauge on the packed moist sand. Rotate the GeoGauge no more that 1/4 of a revolution by holding the side or bottom of the gauge. Now you can take the measurement. When adding water to the mortar sand, there is not enough water if it does not clump when squeezed in your hand. There is too much water if water squirts between your fingers. It is essential to be consistent in using moist sand and in the seating of the GeoGauge. The influence of the moist sand in the measurement is negligible.

Use just enough moist sand that when the GeoGauge is placed on it, the sand does not bunch up and touch the bottom of the internal or exterior flanges. It is important that no sand or other material come into contact with the foot flanges or the underside and sides of the GeoGauge body. Only the ring foot surface should contact the soil. A small area on the sides of the ring foot may touch the soil if the soil there is loose.

Dry sand or other cohesionless materials do not help the seating of the GeoGauge. In fact dry sand will serve to decouple the GeoGauge from the ground.

7.0: Sequence Of Operations For A GeoGauge Stiffness/Modulus Measurement

Making Stiffness Measurements With The GeoGauge Per The Following Procedure Conforms To ASTM D6758

- **Inspect The Condition Of The GeoGauge Prior To Testing**
 - 1) Is the foot clean and free of soil and other debris?
 - 2) Is the rubber seal in good condition?
- **Turn On The GeoGauge** (press "ON" button)
 - 1) The self-test will be run (electronics functionality).
 - 2) Ensure battery voltage is adequate (> 7.5 V).
 - 3) No warm-up required before measurements.
- **Prepare The Surface To Be Tested** (see Site Preparation)
 - 1) Is the surface smooth and level?
 - 2) Coarse aggregate, hard surfaces or stiff clay may require moist sand to be patted on the surface for good direct contact with the foot.
 - 3) Ensure the gauge has clearance on the side and bottom, does not come into contact with a trench wall, pipe, soil, etc.
- **Enter Data**

Enter target stiffness from pre-defined, scrolled list via display, if necessary.
- **Verify GeoGauge Operation (daily)**

Perform a check of GeoGauge operation per the GeoGauge Verifier Mass Guide (see Appendix 4). The GeoGauge is operating properly if the mean stiffness is within approximately -8.6 MN/m and -9.8 MN/m.
- **Establish GeoGauge Precision (daily)**

Locate some compacted material that is representative of what is to be measured that test day. Make a minimum of 3 measurements at the same test location. GeoGauge precision is sufficient if the coefficient of variation of the measurements is less than 10%.
- **Seating Of The Foot**

How to properly seat the foot will be determined by on-site trial per the recommendations above (see GeoGauge Seating).
- **Take The Measurement** (press "Meas" button)
 - 1) GeoGauge will measure noise as a function of frequency.
 - 2) GeoGauge will measure stiffness as a function of frequency.

3) GeoGauge will display, in sequence:

- Signal to Noise ratio (SNR) in dB [The stiffer the material, the closer this value will be to 10, indicating that more than usual attention should be paid to seating.]
 - The standard deviation (5d) of all 25 frequency dependent stiffness measurements relative to the displayed (average) value of stiffness [This number will be small for soft materials (~ 1 MN/m) and larger for hard materials (~ 5 MN/m). A large change in this number between test locations for a given material may indicate improper seating (e.g., from 1.5 to 3 MN/m). A measurement should be repeated at such a location to assure proper seating. If the measurement does not change, then it is a true representation of the material.]
 - Stiffness or Young's modulus or fraction of stiffness Target
 - Ready for next measurement (last measurement value still displayed)
- **Remove The GeoGauge From The Test Location**
 - 1) Examine the spot and ensure good foot contact (see GeoGauge Seating).
 - 2) Clean any soil off of the foot that may have been caked on in the course of testing.
 - **Store Data** (press "SAVE" button)

The measurement ID will be assigned to the stored data. The GeoGauge will store data for 500 measurements as displayed (Operational Mode). Only the first 20 measurements stored will also include the complex, frequency dependent components of displayed data (Research Mode).
 - **Turn The GeoGauge Off** (press "OFF" button)

When done for the day, turn off to save battery power.
 - **Transfer Data (via optional Infrared interface)**

Download data to a PC per GeoGauge Data Download Guide (see Appendix 5).

8.0: Transit - Carrying Case

The transit case has both key lock and combination lock. The combination is set at factory "0-0-0". To re-set the combination number:

- 1) Open the case. Looking at the back of the lock inside the case you will see a change lever. Move this change lever from the normal position to the middle of the lock in the way that it hooks behind the change notch. Move it sideways and then up.
- 2) Now you set your combination number by turning the dials to the desired three number combination. Record the numbers below.
- 3) Move the change lever back to its normal position.
- 4) To lock, close the case securely and rotate one or more of the dials. To un-lock, set the dials to the proper numbers.
- 5) Record the numbers _____ - _____ - _____
- 6) The key lock/latch set requires the attached key to lock.

9.0: Replacing Batteries

Model H-4140 requires six (6) size "D", 1.5 volts dry cell alkaline batteries. Three (3) batteries in each of the two battery compartments, accessible via two screw-on caps on the top of the GeoGauge. Replace all batteries with a fresh set. Attempting to mix fresh batteries with used batteries will cause the fresh batteries to deteriorate very quickly to the level of the used batteries, negating any advantage of fresh batteries.

- 1) Turn off gauge. Remove the battery caps by unscrewing counter-clockwise. A suitable coin may be helpful to loosen them.
- 2) Carefully lift and remove the spring and the battery contact retainer.
- 3) Remove the batteries, tilting and turning the gauge upside down will facilitate removal.
- 4) Insert the fresh batteries with the positive (+) side up in both compartments.
- 5) Carefully insert the battery contact retainers and springs and then screw on clockwise the battery caps. There is an o-ring seal on the underside of the battery caps to seal out water and dirt. Hand tighten only. Occasionally during use insure that the battery caps are tight.
- 6) Loosen the four (4) corner captive screws with a Phillips screwdriver. Remove any static electricity in one-self by touching a metal earth grounded object such as the back of a computer housing.
- 7) Carefully lift up the display panel which contains the electronic circuitry on the underside. On the left side are two toggle switches, #1 and #2.
- 8) Switch #1 to on as marked. Turn on the unit by pressing the "ON" button. The display will momentarily show reset and then revert to its normal display.

- 9) Turn the #1 switch to off. Turn off the unit by pressing the "OFF" button. Replace the display panel back onto the unit and lightly tighten the screws. The GeoGauge is ready for operation.

Note: The gauge exterior is not water proof or dust proof. Attempts were made to make the gauge as tight as reasonable. Do not expose the gauge to precipitation. Should the gauge get wet, exposed to high humidity or suspected of containing moisture or condensation, immediately dry out the gauge by removing and gently setting aside upside down, without disconnecting the wires, the display panel and battery caps and batteries. Allow to air dry in a dry enough room overnight. Carefully re-assemble before using or packing back in case.

10.0 Clock / Date Adjustment

Purpose

The clock is used to stamp the time and date of each stiffness measurement. When saved the measurements can be downloaded into a PC onto a spreadsheet template to analyze the complex data from the first twenty measurements saved. Saved measurements number 21 to 500 show only the run #, stiffness value and time/date. Changing the batteries will not delete or lose the clock settings.

Operation

- 1) With the GeoGauge "ON" and in normal mode, press the "SHIFT" button and then the "MEAS" button to get into the user input mode. The Poisson's Ratio values will display. Press "SHIFT" and "MEAS" buttons again, the clock settings should display.
- 2) The "-" represents AM. The "+" represents PM. Pressing the "INCR" or "DECR" will scroll the values up or down.
- 3) With the first pressing of the "SHIFT" and "MEAS" buttons from step #1 and the clock displayed, both time and date, the hour will adjust. Scroll to the correct hour and AM or PM.
- 4) Pressing the "SHIFT" and then the "MEAS" buttons again will allow adjustment of the minute. Scroll to the correct minute.
- 5) Pressing the "SHIFT" and then the "MEAS" buttons again will allow adjustment of the month. Scroll to the correct month.
- 6) Repeat for day and then year. Continuing the adjustments will rotate back to hour, then minute, then month, then day, then year.
- 7) At anytime, if you are satisfied with the settings, press the "SAVE" button, and then press the "OFF" button to get out of the clock adjustment mode. Press "ON" to turn on unit for measurements.

Appendix 1

Stiffness Based Compaction QC Method

CASE STUDY:

Stiffness Based Compaction QC of a Granular Subgrade

Minnesota DOT
District 2
423 West Zeh St.
Thief River Falls, MN 56721

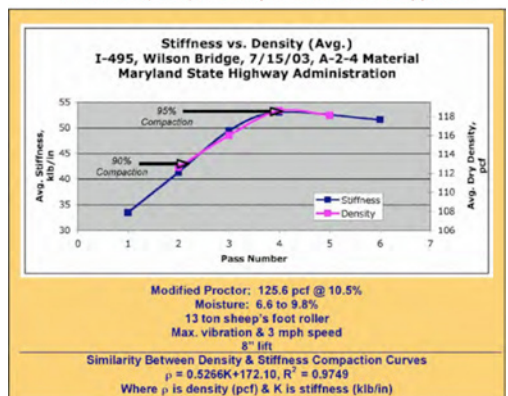


Traditional subgrade compaction QC test methods do not evaluate in-place material strength or the structural uniformity of each lift as placed. Evaluating these two factors is essential if cost is to be held to a minimum while assuring the performance needed for the roadways intended function and projected life. This type of evaluation is essential if the industry's trend towards modulus based mechanistic design and performance specifications for roadways are to be supported. Also, traditional methods do not provide contractors with sufficient real-time feedback so as to optimize the balance of quality and cost.

Accordingly, a simple and precise modulus or stiffness based QC test method for subgrades was needed by the Minnesota Department of Transportation (MnDOT), District 2, Thief River Falls Construction Office that would evaluate the required factors as compaction occurs. At the same time this method needed to provide an index of percent compaction so as to fit within the framework of traditional specifications. Finally, the method needed to provide an index of resilient modulus to support the future use of mechanistic design and performance specifications.

District 2 selected an in-place QC test method developed under FHWA Study 2(212) that did not interfere with or delay the construction process. Without penetrating the ground, the method used the Humboldt GeoGauge to measure the stiffness of each lift and thereby evaluate percent compaction. Using a test section or strip of subgrade material, lift stiffness at controlled moisture content was measured and spatially averaged as a function of compactive effort. Initially this data was compared to density as a function of effort to confirm the findings of FHWA 2(212) that maximum stiffness occurs at optimum compaction as constrained by site conditions. The resulting empirical relationship was used to establish QC stiffness targets for the subgrade that corresponded to the traditionally specified levels of percent compaction.

FHWA 2(212): Compaction vs. Stiffness



The Humboldt GeoGauge is a 10" diameter, 11" tall, 22 lb. electro-mechanical instrument that when placed on the surface of the ground evaluates the stiffness of the top 9" to 12" of material. It vibrates the ground over a range of discrete frequencies, applies force, measures the resulting deflection and displays the results in about a minute. It was chosen by MnDOT District 2 because measurements could be made at a rate greater than the rate of compaction, it has no licensing or safety requirements and its performance (reliability, precision & bias) had been proven by FHWA Study 2(212) & TRB NCHRP Project 10-65.

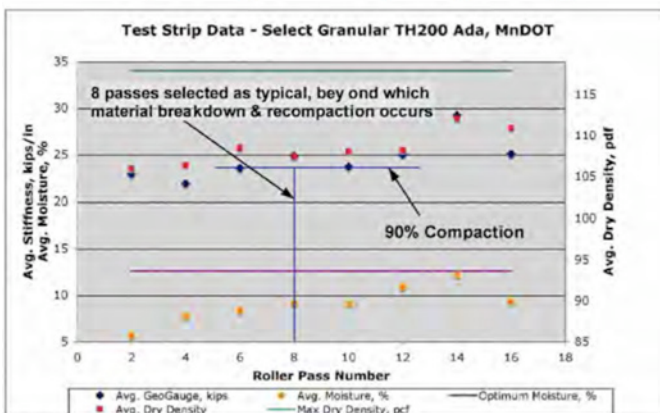


**Humboldt
GeoGauge**

In the summer of 2004, District 2 chose road TH200 in Ada, MN for its initial use of this QC test method. The method was contractually specified. This was the only way District 2 thought that sufficient data could be collected for a comprehensive evaluation of the method. The subgrade was an AASHTO A-1-b material, placed in two 12" lifts over two miles of 2-lane roadway. Stiffness was measured approximately every 100 ft. on each lane for each compacted lift, one 1,000 ft. section at a time. Based on test strip measurements at the start of the project, a stiffness value of 23 klb/in was assigned as a target corresponding to the specified 90% compaction. Moisture was measured approximately every 500 ft. by either time-domain-reflectometry or field oven. Density was measured randomly as a check on the method and took precedence in judging quality if there was a conflict with stiffness.

The over 1,000 stiffness QC tests made on the TH200 project indicated that the level of compaction was from 87% to 97% (18.2 klb/in to 32.2 klb/in for 95% of the data). This was better than the best quality traditionally possible for the material in District 2's experience. Moisture content was typically 3.5% below optimum, varying from about 6% to 12%. This was consistent with the best quality traditionally possible.

Test Strip: Assignment Of Target Stiffness



The level of material compliance with the specification and small variability in the quality of compaction was unprecedented in the experience of MnDOT District 2. The real-time nature of the stiffness QC tests forced the continuous attention of the contractor to compaction quality as was evident by the section-by-section adjustments in roller patterns and watering. This real-time attention to quality also resulted in a significant reduction in the contractor time and effort traditionally needed to accomplish this kind of job.

The material strength achieved and its uniformity, as evident from the stiffness tests, was consistent with supporting a 20-year roadway life. According to FHWA guidelines, A coefficient of variation (COV) of less than or equal to 20% in subgrade strength will support a 20-year life. The COV achieved for TH200 was less than 14%.

District 2 found that the material and construction uniformity enabled by this test method was sufficient to require stiffness testing intervals of no smaller than every 500 ft.

Since the completion of the TH200 job, the stiffness measurements made as part of the test method has been shown to have a strong relationship to resilient modulus and so are useable as an in-place index¹.

District 2, Thief River Falls Construction Office, of the Minnesota Department of Transportation has deemed the success of this first use of stiffness based compaction QC testing sufficient to warrant continuing and broadening use of it on subgrades and bases in the 2005 and 2006 construction seasons.

For more information contact:

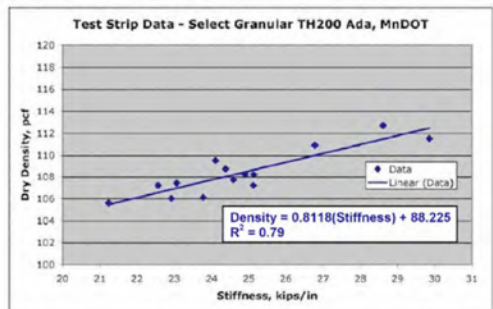
Melvin Main, Humboldt Mfg. Co.
717-650-6537,
melmain@humboldtmfg.com

or

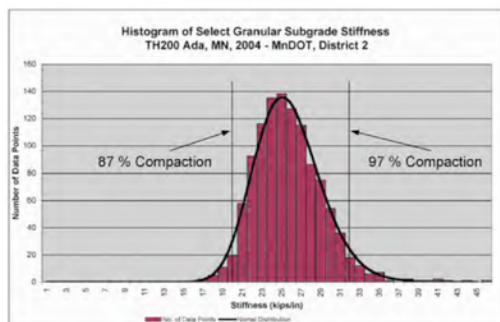
J. T. Anderson
Resident Engineer,
MnDOT District 2
216-681-0927

J.T.Anderson@dot.state.mn.us

Test Strip: Stiffness vs. % Compaction (Density)



QC Test Data



¹ Development Of Resilient Modulus Prediction Models For Base And Subgrade Pavement Layers From In Situ Devices Test Results, 2004, Ravindra Gudishala, Louisiana State University, Baton Rouge, LA 70808

Appendix 2
Stiffness Based QC Method
Used On A Stabilized Base

CASE STUDY:

Micro-Cracking A Cement Treated Roadway Base To Minimize Shrinkage Cracks

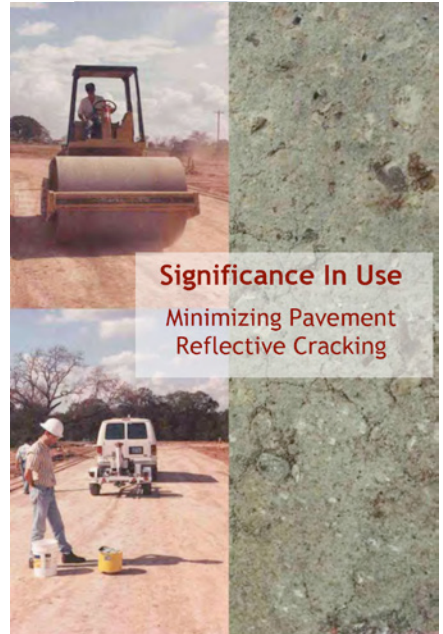
Texas A&M University
The Cities of Bryan & College Station, TX
The Cities of La Quinta & Santa Rosa, CA
CEMEX

For decades, cement-amending a roadway base has been a way of employing economical local materials in place of imported, high cost aggregate. These bases have the strength and low water permeability to potentially out perform flexible aggregate bases. Unfortunately, cement-amended bases are prone to significant shrinkage cracking that concentrate and reflect traffic stress resulting in premature pavement cracking sufficient to warrant repair or rehabilitation. Consequently, cement-amended bases have seen limited use over the last twenty years.

A simple and economical construction method has been developed in Europe and implemented in the United States that minimizes shrinkage cracking in these bases. Dr. Tom Scullion of Texas A&M University accomplished the implementation in response to a request from the City of College Station, Texas¹. The method included aspects that have been under investigation for many years such as controlling the amount of cement used (3% to 9% by weight), the water content, the quality of the subgrade and the type & time of final surfacing. What was new in the method was the controlled induction of micro-cracks into the base. The micro-cracks prevent the development of the larger shrinkage cracks without significantly impacting stiffness of the base.

The performance of the mix was first verified through a series of unconfined compressive strength tests in the laboratory. A strength of 300 psi to 500 psi was required with around 300 psi considered optimal.

During the first two days of life, the stiffness of the base was evaluated to assure sufficient ultimate strength. The 6" to 12" lifts addressed by the method had to achieve a stiffness of about 50 to 60 Mega Newtons per meter (MN/m) during this period. At the end of this period, limited vibratory rolling (1 to 4 passes) using a 12-ton, steel wheel roller was conducted to lower base stiffness by about 40% and thereby induce a network of micro-cracks. Stiffness was directly measured in real-time without penetrating the base using the Humboldt GeoGauge.



¹ Field Investigation: Pre-Cracking of Soil-Cement Bases to Reduce Reflection Cracking, 2001, Tom Scullion, Texas A&M University, College Station, TX 77843

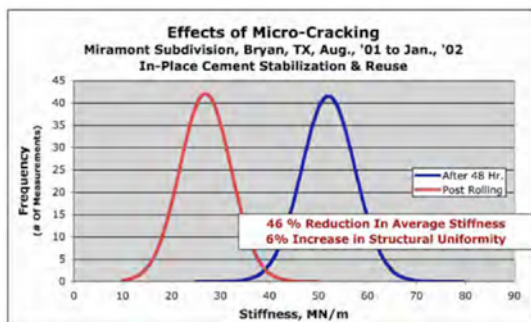
The Humboldt GeoGauge is a 10" diameter, 11" tall, 22 lb. electro-mechanical instrument that when placed on the surface of the ground evaluates the stiffness of the top 9" to 12" of material. It vibrates the ground over a range of discrete frequencies, applies force, measures the resulting deflection and displays the results in about a minute. It was chosen by Texas A&M because measurements could be made quickly, it has no licensing or safety requirements and its performance (reliability, precision & bias) had been proven by FHWA Study 2(212).

Four sections of Salzburg Ct., Von Trapp Ct., Newburg Ct. and Sophia Lane in College Station, Texas were constructed during October of 2000. The construction consisted of 6" of lime-stabilized subgrade, 6" of soil-cement and a 2" HMA surfacing. The Salzburg Ct., Von Trapp Ct. and Newburg Ct. Sections received the stiffness control and the micro-cracking. The Sophia Lane section did not. Site conditions were generally wet during construction. Bob Mosley, City Engineer for College Station, supervised the work. Young Brothers, Inc. accomplished the construction.

The micro-cracks were observed to greatly inhibit base shrinkage cracking. Laboratory testing of core samples indicated that the base reached its design strength. Apparently the micro-cracks were induced early enough in its life so as not to significantly inhibit strength gain. In more than 18 months of observations, the roadway sections constructed with the micro-cracking method exhibited at least 50% fewer reflection cracks in comparison to the section that did not. A corresponding reduction in roadway maintenance cost was also observed.

Texas A&M's results prompted the City of Bryan, Texas to specify the construction method in 2001². As shown in the figure below, the QC test data followed the results achieved in the Texas A&M study. The City of Bryan has successfully used the method through the 2005 season. The City of College Station, Texas followed suit shortly after College Station, adopting the City of Bryan's specification for continuous use.

QC Test Data: Bryan, TX



During 2004, CEMEX, the second largest supplier of cement products in North America, began to promote the use of the micro-cracking construction method in southern California. This prompted the adoption and successful use of the Bryan, Texas specification by the Cities of La Quinta and Santa Rosa, California in 2005. As shown in the figures below, the QC test data is very similar to that achieved in Texas three years earlier. The construction method apparently affords consistent results job-to-job even with the expected variabilities in materials and construction. CEMEX has also secured commitments from several other southern California cities to use the method. In 2006, CEMEX will expand its promotion of this construction method to include all of the southwestern United States and Mexico.

During 2005, the Montana Department of Transportation judged the benefits sufficient to adopt the Bryan, Texas specification for use during the 2006 construction season.

For more information contact:

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or

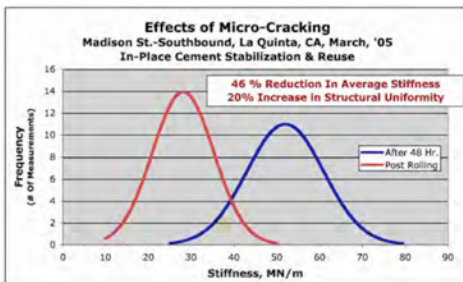
Dr. Tom Scullion, Texas A&M University,
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979-778-2810, rconlin@txcyber.com

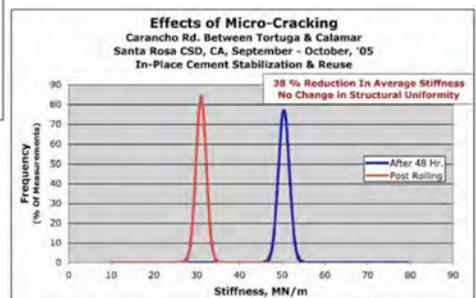
Steve Speer, City Engineer, City of La Quinta, CA,
760-777-7043, sspeer@la-quinta.org

Jeff Wykoff, Manager of Business Development, CEMEX,
909-238-8350, jefferyp.wykoff@cemexusa.com

QC Test Data: La Quinta, CA



QC Test Data: Santa Rosa, CA



Appendix 3
Stiffness Based QC Method
Used On A Stabilized Subgrade

DATA ANALYSIS SUMMARY:

Lime Stabilized Subgrade

Virginia Route 288

February, 2003

PREPARED FOR:

Koch Performance Roads, Inc.

4111 East 37th Street North

Wichita, Kasas 67220

The following represents an effort by Koch Performance Roads to quantify the performance of approximately 50 miles of lime stabilized, silty clay, ~ 12" thick subgrade which was part of the Koch managed reconstruction of Virginia (VA) Route 288. As with similar jobs managed by Koch (e.g., NM 44), the traditional 7 day waiting period between subgrade installation and resumption of construction was inconsistent with Koch's aggressive construction schedule. To reduce the waiting period, Koch needed a QC method that could quantitatively estimate when the subgrade was strong enough to support construction and estimate subgrade ultimate strength. The method would have to determine these factors from measurements made within the first few days after installation. Limited measurements made on a similar lime stabilized subgrade of New Mexico 44 in 2000 indicated that evaluating a material modulus vs. time might provide the needed method. This was accomplished by calculating a modulus from measurements of lift stiffness made using the Humboldt GeoGauge. To confirm this, a comprehensive evaluation of subgrade lift stiffness was conducted on VA 288. The construction specification used on NM 44 was also used on VA 288. The NM 44 data established that a modulus calculated from lift stiffness could be used as the estimate of strength. If the VA 288 subgrade performance was consistent with the subgrade of NM 44, then stiffness based QC of the lime stabilized subgrade is indeed viable if not a practical and form the basis for a specification.

From the sum of the data provided by Koch, it appears that the effective modulus of the lime stabilized subgrade increases with time at a logarithmic rate to a good degree of correlation (see Figure 1). This data also shows that of the approximately 1,000 measurements made on the subgrade, approximately 95% fall within +/- 36% of the average modulus. Based on FHWA, Office of Pavement Design guidelines, this variability in subgrade modulus could support a 15+ year pavement life. The modulus and rate of change of modulus with time for the NM 44 lime stabilized subgrade from over two years prior falls within the data range for VA 288. Also, core testing by Koch was consistent with the modulus data. Where modulus data fell within +/- 36% of the average, the corresponding strength data was acceptable.

The modulus cure rates for the individual sections generally follow that of the average (see Figure 2). The correlation coefficients are not as good, but do they need to be for QC/QA purposes? All data provided was used for the analysis with the exception of the following:

- tsg01_VA288, 10/24 to 10/29 (discarded for poor measurement quality [precision])
- Main Line_ NBL_...2 to 196+57, 7/18 to 7/25, Day 8 (questionable data quality [missing information])

Additionally, the data from loop D_ Sec E _...Interchange, 7/18 to 7/22 was used because of good measurement quality, but the data indicates that changes in the site conditions may have influenced the cure rate in an unexpected way.

Figure 3 shows the number of data points used in the analysis by day in the cure cycle, almost 1,000 points. This is many more than the 84 data points used to determine the NM 44 cure rate. The fact that the correlation coefficients for the 11 sets of cure rate data are typically not as good as that for the one data set from NM 44 leads me to believe that the cure rates in the VA288 data may be masked by changing site conditions (e.g., temperature, moisture, traffic, material differences, installation practice, ...). Based on first hand observations, these types of conditions changed very little on NM 44. I suggest that minimizing the effect of these variables should influence future section and test date selection.

Tables 1 and 2 contain the summary data used in the figures.

In my opinion, Figure 1 embodies the basis for a trial specification. Effective modulus should be within $\pm 2\sigma$ of the target modulus (average) 95% of the time on any given day after installation. This specification may be unique to the general materials and construction methods used. Also, such a specification should include a practical spatial sample for QC testing (e.g, every 500 ft.). Figure 1 also suggests that such a specification may be largely independent of site conditions or even job site.

Figure 1

VA 288 Lime Stabilized Subgrade Charterization of Modulus vs. Time

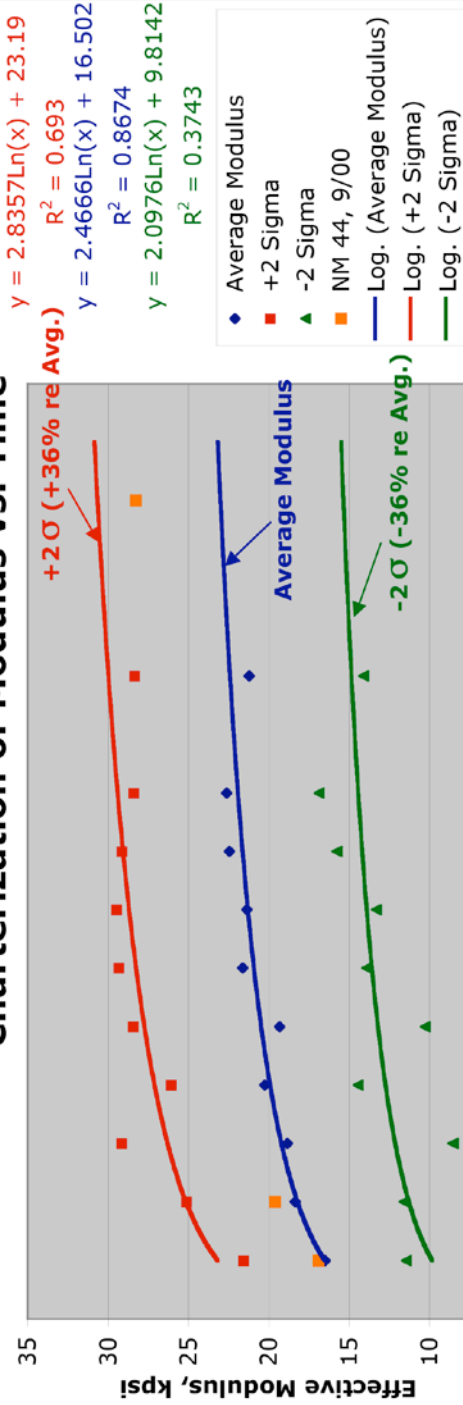


Figure 2

VA 288 Lime Stabilized Subgrade Modulus vs. Time By Section

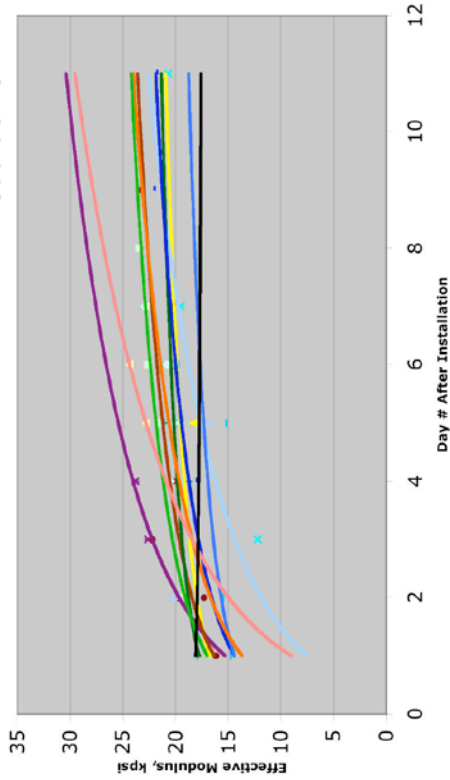


Figure 3

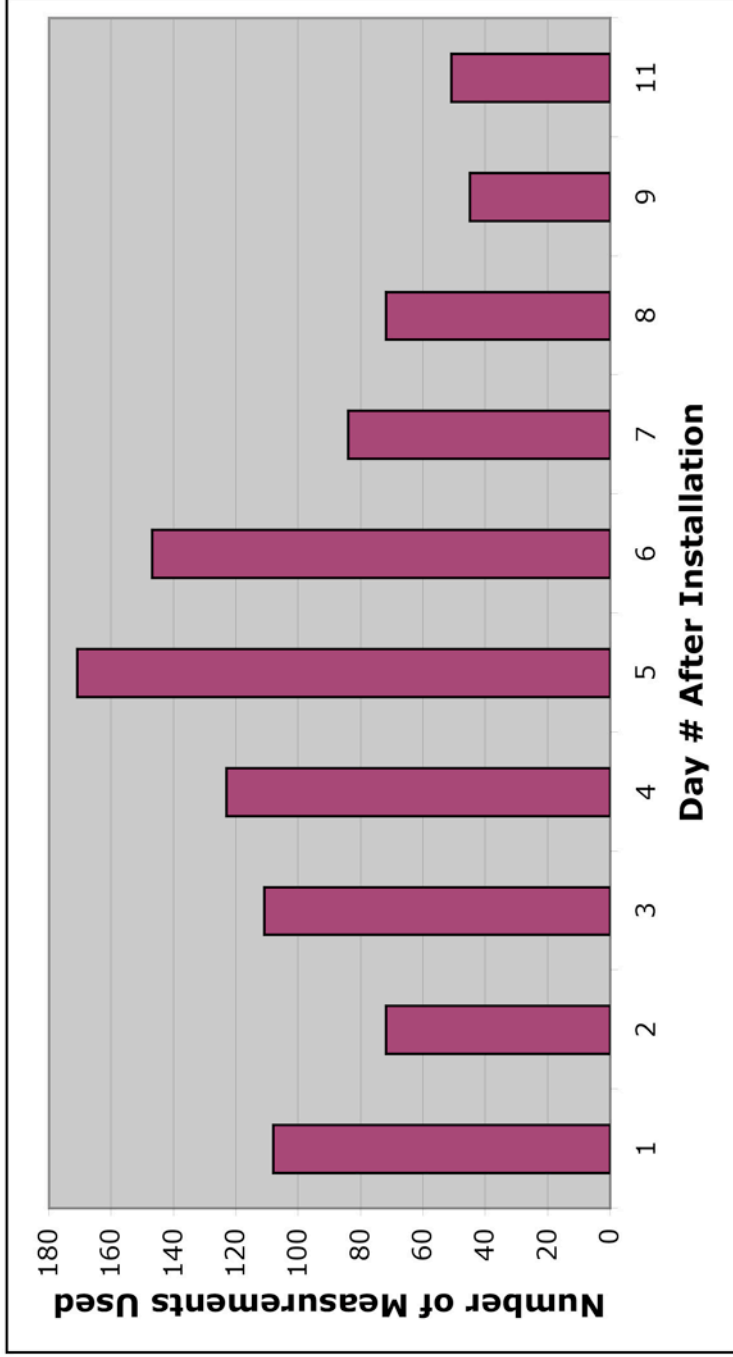


Table 1

Day #	1	2	3	4	5	6	7	8	9	11	14
Number of Data Points	108	72	111	123	171	147	84	72	45	51	
Average Modulus, kpsi	16.5	18.3	18.8	20.2	19.3	21.6	21.4	22.4	22.6	21.2	
Standard Deviation, kpsi	2.5	3.4	5.2	2.9	4.5	3.9	4.0	3.3	2.9	3.6	
COV, %	15.4	18.5	27.4	14.4	23.5	17.9	18.9	14.9	12.8	16.8	
AVERAGE+20, kpsi	21.6	25.1	29.2	26.1	28.4	29.3	29.5	29.1	28.4	28.3	
AVERAGE-20, kpsi	11.4	11.6	8.5	14.4	10.2	13.9	13.3	15.7	16.9	14.1	
NM 44, Avg. Modulus, kpsi	16.9	19.6									28.3

Table 2

Location:Station	Source:File	Date	Avg. Temp., °F	1	2	3	4	5	6	7	8	9	10	11
10+16 to 17+70	1sg01_VA288	10/24 to 10/29	43.8	16.9	20.1			30.8						
NM 44	NM44			19.6				23.7						
10+97 to 15+30	Ramp A, Sec D	7/25 to 7/30	76.0	16.9				18.3						
186+45 to 189+67	MTD_GeoGauge	5/20 to 5/28	76.3			12.2		19.6	21.0					
134+50 to 141+31	Main Line_SBL...0 to 141+31.xls	8/16 to 8/14	86.7		19.5	22.6	23.8		21.1	19.5				20.7
132+98 to 135+57	Main Line_NBL...8 to 135+57.xls	8/6 to 8/14	70.4	16.2	17.3	22.2	20.2			20.3				
144+24 to 149+71	Main Line_NBL...4 to 145+71.xls	8/2 to 8/6	76.3	17.9			18.8							
135+90 to 141+74	Main Line_NBL...8 to 135+90.xls	8/7 to 8/15				18.4	18.0							
200+42 to 196+57	Main Line_NBL...2 to 196+57.xls	7/18 to 7/25	91.3	14.8	15.5			15.1	19.7					21.7
195+32 to 193+51	Main Line_NBL...2 to 193+51.xls	7/29 to 8/1	87.6				20.4	19.6	20.8	22.9				
129+62 to 131+44	Main Line_NBL...2 to 131+44.xls	8/9 to 8/15	70.6		19.2			21.4	22.6	22.7				23.5
130+00 to 133+97	Main Line_SBL...8 to 133+97.xls	8/14 to 8/15	88.1					22.8	24.4					
11+27 to 13+20	loop D_Sec E...interchange.xls	7/18 to 7/22	90.6	16.8	20.2			16.8						

Appendix 4
GeoGauge® Verifier Mass Guide

Humboldt GeoGauge® Verifier Mass Guide

For use with C series Humboldt GeoGauge

Purpose

To verify or check the operation of the C series Humboldt H-4140 GeoGauge by running a measurement on top of the Verifier Mass. It is not intended to calibrate the GeoGauge.

Equipment Required

H-4140.20 Verifier Mass Assembly (10 kg with installed rubber isolation mounts)

Operation

- 1) Place the Verifier Mass Assembly on a relative flat and rigid surface. The surface at this location should be approximately level. A concrete floor that is generally crack-free and well supported is ideal.
- 2) Wipe clean the ring foot at the bottom of the GeoGauge. Clean the v-groove around the seal between the foot and gauge body. Inspect the ring foot surface for deep gouges, nicks, protrusions or raised nicks. The ring foot should be relatively flat. Remove excessive protrusions or raised nicks by setting the GeoGauge on a flat abrasion sheet placed on a flat steel plate. Rotate the GeoGauge via its handle 2 – 3 times until the protrusions are approximately flat with the ring foot surface. Wipe off the abrasion dust from the ring foot.
- 3) Turn on GeoGauge. Set the GeoGauge to display stiffness in S.I. (metric) units.
- 4) Smear a small amount of any lubricating oil on the shoulder of the Verifier Mass.
- 5) Gently set the GeoGauge's ring foot in position over the shoulder of the Verifier Mass.
- 6) Rotate the gauge on the mass a random amount.
- 7) Firmly press the MEAS button to make a measurement of the Verifier Mass stiffness.
- 8) After 75 seconds the measured stiffness will be displayed. Record the stiffness.
- 9) Remove the GeoGauge from the Verifier Mass. Reset it back onto the Verifier Mass. When repeating measurements, it is important to remove the GeoGauge from the Verifier Mass between measurements to account for placement and operator bias. Place the GeoGauge on the Verifier at different rotational orientation each time.

- 10) Normally, five (5) measurements will be sufficient. Average the measurements for a result. Record all measurements and save the records for long term monitoring of GeoGauge operation. The values from each verifier measurement will oscillate up and down a small percentage and the average stiffness should be used to compare with the expected stiffness. It is not necessary to verify daily. Weekly or once a month or when questions about the validity of the stiffness/modulus measurements occur, then the use of the Verifier Mass is justified.
- 11) An average stiffness of roughly -8.6 to -9.8 MN/m is expected on the Verifier Mass. If this is not achieved, contact Humboldt for assistance.

The GeoGauge is built to withstand normal field instrument handling. The gauge can still be damaged from mishandling and abuse. It cannot be over-emphasized that proper care and maintenance will give the owner long life and reliability from the instrument.

Appendix 5

GeoGauge® Data Download Guide

Humboldt GeoGauge® Data Download Guide

For use with C series Humboldt GeoGauge

Purpose

To download data from the C series Humboldt H-4140 GeoGauge to a PC.

Equipment Required

- H-4140.12 Infrared Interface to serial port cable
- USB to serial port adapter (optional)
- Any PC running any version of Windows with HyperTerminal

Operation

Initial Setup

- 1) Attach the GeoGauge Infrared Interface Cable to a 9 pin serial port on the personal computer (PC) or to a USB port via an appropriate adapter (Figures 1, 2 & 3).
- 2) Attach the GeoGauge Infrared Interface Cable reader head to the slotted retainer on the top of the GeoGauge. Be sure that the two infrared windows line up (Figure 4).
- 3) Turn on GeoGauge and PC.
- 4) On the PC monitor, click "Start", highlight "Accessories", click "Communications", and click "HyperTerminal". HyperTerminal is the Windows terminal emulation program.
- 5) Enter a distinct file name for the GeoGauge download settings. For example: "GeoGaugeDownload". Select an appropriate icon. Click "OK". It is through this new connection setting that all download data can be entered repeatedly without having to re-enter the settings every time.
- 6) In the "Connect To" window, select "connect using". Highlight the COM port to which the Infrared Interface Cable is connected. Click "OK".
- 7) In the "COM Properties" dialog box under the "Port Settings" tab, show:
 - Bits per second: 4800 (for GeoGauge serial numbers less than 326) or 1200 (for GeoGauge serial numbers greater than or equal to 327)
 - Data bits: 8
 - Parity: none
 - Stop bits: 1
 - Flow control: HardwareClick "OK"; click "File" and then click "Save".

Data Downloading

- 1) Repeat operations 1, 2 and 3 above.
- 2) Double click on the HyperTerminal icon selected earlier.
- 3) In the window that opens, Click "Transfer". Click "Transfer Text". Create a file for the data to be saved in. A new file name will have to be entered for each new download. A unique reference number and date are suggested. The file name must end with ".csv".
- 4) Press the "Shift" key and then the "Print" key on the GeoGauge. Data should be seen streaming onto the screen immediately. The data should look like the example in Figure 4.
- 5) When the data stops streaming, click "Transfer", highlight "Capture Text" and click "Stop". Click "Call". Click "Disconnect". Click "File". Click "Save".
- 6) Confirm that the data was saved by opening the .csv file in Microsoft Excel. Close HyperTerminal. Figure 5 is an example of what a typical .csv file should look like.
- 7) Press the "Shift" key and then the "Erase" key on the GeoGauge. This will permanently erase the data just downloaded.
- 8) Repeat 2 through 8 each time data is downloaded.

The .csv files can be "cut & pasted" into an Excel spreadsheet. Humboldt supplies Excel templates for various uses with these files. Contact Humboldt for further information or for help in developing a custom spreadsheet.

Contact: Mahir_AL_Nadaf

Humboldt Scientific, Inc., 2525 Atlantic Ave., Raleigh, NC 27604 U.S.A.

Voice: 919.832.6509, Fax: 919.833.5283, Email: mahir@ehumboldt.com



Figure 1
H-4140.12
Infrared Interface To
Serial Port Cable



Figure 2
Typical Serial To
USB Adapter



Figure 3
GeoGauge
Connected To A PC

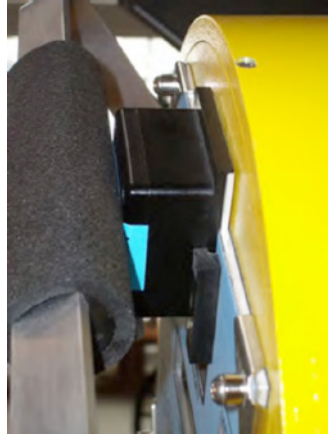
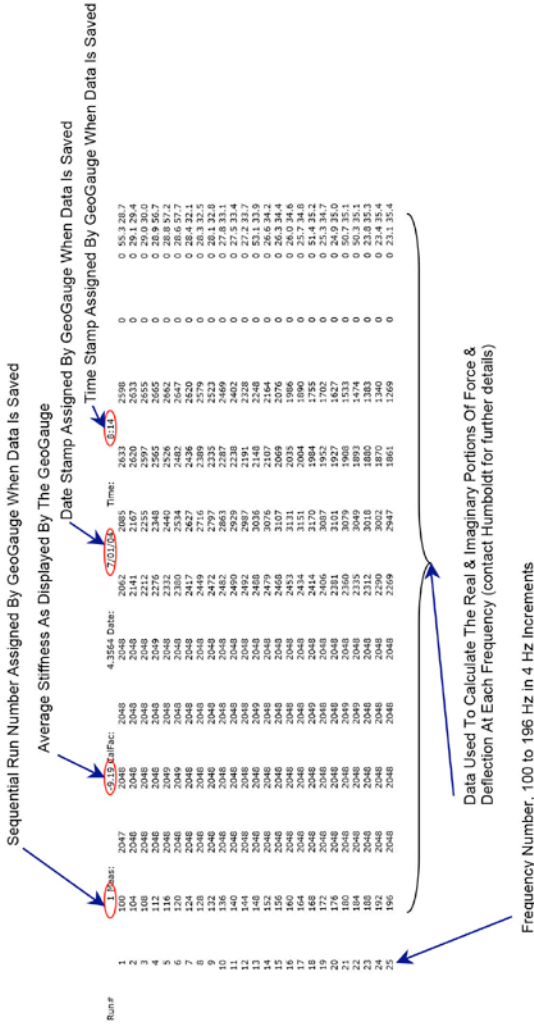


Figure 4
Proper Orientation of
Infrared Sensor on
GeoGauge



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Testing Equipment for

Construction Materials

HUMBOLDT

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