FINAL PROJECT REPORT

REPORT TITLE: **Development of a Non-Nuclear Soil Density Gauge to Eliminate the Need for Nuclear Density Gauges**

REPORT DATE: **October 31, 2008**

PERIOD COVERED: **May 15, 2007 through October 31, 2008**

REPORT NUMBER: **Phase II Final Report**

PREPARED FOR: **US Dept of Homeland Security**
Domestic Nuclear Detection Office
245 Murray Lane, SW Bldg 410
Attn: John Zabko
Washington, DC 20528

UNDER CONTRACT: **HSHQDC-07-C-00080**

PREPARED BY: **TransTech Systems, Inc.**
1594 State Street
Schenectady, NY 12304-1529

D. D. Colosimo (518) 370-5558

Table of Contents

1.0 SUMMARY

This report provides the results of the DHS SBIR Phase II contract HSHQDC-07-C-00080 titled, "**Development of a Non-Nuclear Soil Density Gauge to Eliminate the Need for Nuclear Density Gauges.**" The report also includes work that was performed under a concurrent and supporting contract from the New York State Energy Research and Development Authority (NYSERDA). The objective of these programs is to develop and commercialize a non-nuclear replacement for the Nuclear Density Gauge (NDG).

In the past few years, Congress and various government agencies have recognized the problem of orphaned radioactive sources worldwide. Such sources pose a security risk in the form of potential material for a "dirty bomb" or for other illicit applications. Non-nuclear sources or techniques are sought to replace the many radiological sources now in use for commercial applications. The Department of Homeland Security's (DHS) goal is to dramatically reduce the amount of radioactive material in common use in order to improve public security and prevent the diversion of nuclear material.

The nuclear density and moisture gauge (NDG) is widely used in the construction industry to measure the wet density and moisture of soils. This measurement is used as a quality control to assure that the soil is properly compacted to support various kinds of structures. While NDGs are under control when in the laboratory, they are routinely taken to construction sites where they can be lost, stolen or damaged. The NDG provides a potential source for radioactive material which can result in a radiological event, either through intent or accident. Even though there is the theoretical potential for numerous fatalities from radiation exposure from an NDG, the difficulty of achieving optimal dispersion of the radioactive material would probably result in few if any serious injuries due to radiation. However, the economic and psychological effects can be out of proportion to the actual physical danger. There are, however, demonstrated serious environmental impacts due to the improper disposal of the NDG. Since there is a cost associated with the proper disposal of NDGs, there is an incentive for some users to "lose" the units. Some units have ended up in scrap heaps and have contaminated scrap-processing plants, at a cost of several million dollars in clean-up costs per incident.

Even in cases where there is not an overt planned act to discharge the radioactive material from the NDG, these devices are used on construction sites where they can be, and are, accidentally damaged. On December 20, 2006, a backhoe ran over a NDG at an Albany, NY construction site. The local newspaper reported: "Workers and members of the public streamed from the Albany County Judicial Center, the state Court of Appeals, City Hall and homes and businesses in the immediate vicinity during an evacuation around 3 p.m. County sheriff's deputies and Albany police directed traffic while firefighters readied hoses at hydrants near the affected buildings."

This accident in Albany highlights the real danger with these devices. The economic and psychological effects can be out of proportion to the actual physical danger. In the Albany accident, the containers of the radioactive material were not damaged and there was no radioactive material released. Yet, there was significant disruption at a number of government buildings. The actual release of radioactive material would cause a panic and result in people avoiding the area. A purposeful or accidental radiation discharge in key transportation or economic centers could cause serious economic disruptions. Consequently, these nuclear density gauges pose a critical national security issue/concern.

The number of NDGs in use is large. The Nuclear Regulatory Commission (NRC) estimates the number of NDGs in use in the USA by the construction industry for asphalt and soil testing is 22,000-25,000 ["Security Requirements for Portable Gauges Containing Byproduct Material" Federal Register: August 1, 2003 (Volume 68, Number 148)]. The portable nuclear density gauges pose two very critical national issues, security and environment. Since the NDG is under limited control in the field, *each year, approximately 300 of these units are reported lost or stolen to the NRC with only 150 eventually recovered* [GAO-03-804 entitled 'Nuclear Security: Federal and State Action Needed to Improve Security of Sealed Radioactive Sources' released September 09, 2003].

The mission to eliminate access to minimally controlled radiological devices through the development of alternative technology was assigned to the Department of Homeland Security's Domestic Nuclear Detection Office (DNDO). As part of the effort to address this mission, the DNDO awarded Phase I and Phase II SBIR contracts to TransTech. Any proposed alternative technology must achieve the NDG's full operational capability, but without requiring the use of radioactive nuclear materials. The alternative must be cost competitive and have size, weight, power and usability characteristics compatible with the application needs. It must also be able to withstand the temperatures, humidity, vibration, and shock encountered in construction applications.

The objective of the DHS SBIR Phase I and Phase II programs is to develop a non-nuclear alternative for measuring soil density (compaction) and moisture. During the programs, an electromagnetic based soil density gauge has been developed and is moving toward market introduction. The TransTech Soil Density Gauge (SDG) is based on TransTech's proprietary electromagnetic impedance spectroscopy technology. The SDG is designed specifically and solely for the determination of soil wet density and moisture. TransTech already markets a non-nuclear gauge to determine the density of hot mix asphalt, the TransTech Pavement Quality Indicator (PQI). The PQI is also based on an electromagnetic impedance technology but, due to the simpler problem with asphalt, it does not use or require impedance spectroscopy to make the measurements.

This report describes the overall program to develop a non-nuclear soil density gauge and the results.

2.0 TRANSTECH'S NON-NUCLEAR DENSITY GAUGE ALTERNATIVES

Since 1998, TransTech's Pavement Quality Indicator (PQI) has provided a non-nuclear alternative to the NDG for asphalt testing. Shown in Figure 2-1, the PQI performs a single-frequency, electrical impedance measurement from which asphalt density is calculated. ASTM and AASHTO standards now cover its use. Compared to typical NDGs, the PQI is lighter weight, faster operating, just as durable, and comparably priced. With over 2,000 units sold in the U.S. and in over 40 countries worldwide, the PQI has good marketplace acceptance with current sales running over 250 units per year as a practical NDG replacement on asphalt. As discussed previously, NDGs are also used on soil, which, due to moisture content, presents a significantly more difficult measurement challenge.

Figure 2-1. TransTech's Non-nuclear Pavement Quality Indicator (PQI) Model 301

The PQI cannot be used on soil and, therefore, is not a complete replacement for the NDG.

The development of a replacement for the NDG in soil applications is very difficult due to the non-uniformity of soils, the presence of water and other characteristics. In 2002, TransTech initiated an effort to develop a spectrographic electrical impedance-based Soil Density Gauge (SDG) as a non-nuclear alternative for soils testing. The initial objective was to develop a non-nuclear gauge for use in utility road cuts and repairs. At this time, the objective was not to develop a complete replacement for the NDG. Funding for that effort was provided by a consortium of NYSERDA, Northeast Gas Association, Consolidated Edison, and KeySpan (now National Grid), plus a significant commitment of TransTech's own resources.

Figure 2-2. TransTech Soil Quality Indicator (SDG)

Under this initial funding, TransTech was successful in fabricating three generations of the SDG, culminating with the SDG Model 1 (Figure 2-2). Upon learning of the DNDO's objectives, this unit and work provided the basis for a successful proposal to DNDO for the extension of the program to develop a complete replacement of the NDG.

Figure 2-3. SDG Model 100 – Designed, Fabricated and Tested in Phase II

The SDG Model 1 achieved the level of reliability and consistency among the units to permit the development of algorithms to extract density and moisture data from the impedance spectrum from 30kHz to 31MHz. This was demonstrated on a well-graded sandy soil that met the ASTM United Soil Classification System grade SW.

During Phase I, advances were made in the development of the algorithms for determining moisture and wet density. When these algorithms were applied to the data taken for the twenty compaction levels and five moisture levels that were done in the lab, the standard deviation was computed for wet density agreement between the non-contacting SDG and the standard NDG. ***It was concluded that, not only was the agreement between the non-contacting SDG's wet density calculation and the standard NDG wet density measurements high but that, statistically, the readings were identical.***

Figure 2-4. SDG Model 100A – Designed, Fabricated and Tested in Phase II

This work demonstrated that on one specific class of soil that is commonly used in construction projects in New York, the SDG can achieve precision equivalent to the NDG and provide readings that are statistically identical to the NDG.

The primary objectives of the Phase II program were first, the development and fabrication of a pre-production version of the non-nuclear soil gauge and second, the use of these units for testing and data collection in order to extend the algorithms to convert the electromagnetic impedance spectroscopy signal to provide soil density and moisture for soils that are typical of the engineering soils used throughout the country. The program objectives that were achieved are:

1. Designed, fabricated and tested two generations of the SDG, the Model 100 and Model 100A, (see Figures 2-3 and 2-4) which were used in laboratory, field and beta testing and moved the design to a pre-production design;
2. The SDG Model 100A was used as the basis for the design of the production version of the SDG, which is now in production and shown in Figure 2-5;
3. Extended the verification of the algorithms to additional soils across the country through the conduct of field and beta testing; and,
4. Extended the understanding of the impact on the algorithm of soil gradation through laboratory testing.

Figure 2-5. First Production Design of the SDG

There were ten units of the initial version of the SDG, Model 100 (Figure 2-3), that were used in testing at TransTech and at various field locations. Thirty of the later version of the SDG, Model 100A (Figure 2-4), were fabricated during March and April 2008. Some of these units were used in the field test in Texas. The plan for these units is that five will remain with TransTech for continued testing and to support the beta testing and the first production run, five will be provided to organizations such as NYS DOT, WA DOT, Texas Transportation Institute, the University of Texas at Austin and KeySpan Energy (National Grid), all of whom have indicated that they would do additional field testing. The balance of the twenty units will be provided to commercial beta testers who will be purchasing the units.

All of the objectives of Phase II have been met with the commercial introduction of the non-nuclear soil density gauge shown in Figure 2-5.

3.0 TEST PROGRAM

In addition to design and the fabrication of the hardware described in Section 2.0, the major effort of the program was the securing and analyzing of data to develop algorithms to convert the complex impedance spectrum into measurements of soil density and moisture.

In this section, the technical basis for the SDG is presented. A description of the test programs to develop the data and the analytical approach used to develop the algorithms is also presented. Detailed presentations of the data secured is presented in the Appendices.

3.1 Technical Implementation of the SDG

The SDG, shown in Figures 2-2 to 2-5, is externally similar in appearance to the PQI but has major differences in functionality and capability. The key difference is the ability to take a spectrographic reading of the impedance over a range of frequencies up to 31MHz. The use of spectrographic impedance permits the SDG to separate the effects of the variations of density and moisture. Prior to the initiation of Phase I, TransTech successfully addressed the significant challenge of developing an instrument that can provide the necessary range of frequencies, offer the required precision in the readings, and meet the commercial cost goals. This unit, the SDG Model 1, was used in Phase I to demonstrate the ability to extract density and moisture measurements comparable to a NDG. The theoretical basis for achieving this is described below.

The macroscopic interaction of electromagnetic fields with materials is described by Maxwell's equations. Solution of Maxwell's equations requires knowledge of three constitutive properties of the material: the magnetic permeability, the dielectric permittivity, and the electrical conductivity. In general, these parameters are dependent upon material composition, temperature, and the frequency of the applied field. As the permeability of typical soils is nearly that of free space, the soil electromagnetic response is usually dominated by the dielectric properties.

Soil is a mixture of essentially three components: air, stone, and water, with water acting to help bind the stone matrix together. Some researchers have shown that the matrix bulk dielectric constant may be derived from the volume fractions and dielectric constants of the constituents according to the following, empirically derived, soil dielectric mixing equation:

$$k = \left[\theta k_w{}^{\alpha} + (1-\eta) k_s{}^{\alpha} + (\eta - \theta) k_a{}^{\alpha}\right]^{1/\alpha}$$

Here, k is the bulk dielectric constant; k_w, k_s, k_a are the respective dielectric constants of water, stone, and air; θ is the volume fraction of water; η is the porosity (so that $1-\eta$ is the volume fraction of stone, and $\eta-\theta$ is the volume fraction of air); and α is an empirically determined constant, different for each soil matrix [References 1 and 2]. For sandy type soil matrices, $\alpha = 0.46$ has been found to be typical [Reference 2]. Typical values for the component permittivity are: $k_s = 3-5$, $k_w = 80$, and $k_a = 1$. As compaction increases, porosity decreases; the k_s term drives k upward, while the k_a term drives k downward, but because $k_s > k_a$, the net effect is an increase in k (regardless of the value of α, and even if $\alpha < 0$). The mathematics confirms that when you remove the component with the lowest dielectric constant (air), the bulk dielectric constant goes up.

Asphalt, too, is a mixture of essentially three components: air, stone, and bituminous binder. A corresponding asphalt dielectric mixing equation would be:

$$k = \left[\upsilon\, k_b^{\ \alpha} + (1-\eta) k_s^{\ \alpha} + (\eta - \upsilon) k_a^{\ \alpha}\right]^{1/\alpha}$$

with υ and k_b, respectively, the volume fraction and dielectric constant of the bituminous binder. Here, now, the essential difference between soil and asphalt becomes apparent.

For asphalt, the contractor specifies, and rather closely controls, the value of υ. In the asphalt mixing equation, therefore, with k being the measurement, the only unknown is the porosity η. A single measurement at a single frequency (1 MHz in the current model of the PQI) is sufficient to determine the porosity or, equivalently, the density. However, soil is not a manufactured product. So there is a significant variability in the constituency of soil. Further, while asphalt is produced at a high temperature which eliminates water in the mix, soil must have an amount of water in order for it to be compacted.

In soil, there are three primary mechanisms that lend richness to the dielectric spectrum: the free water relaxation, the bound water relaxation, and the Maxwell-Wagner (MW) relaxation. Figure 3-1 is a sketch of a typical soil dielectric spectrum. Here, ε' is the permittivity, ε'' is the total conductivity divided by the frequency, and the dotted envelope is the static conductivity divided by the frequency. It has been shown [References 1 to 5] that the mixing equation should hold in the frequency range between the MW and bound water relaxations.

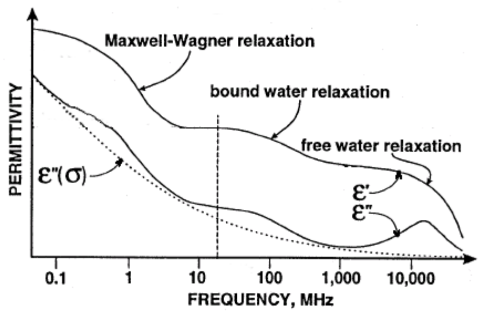


Figure 3-1. Dielectric spectrum of soil (adapted from Hilhorst and Dirkson)

For soil, on the other hand, both η and the volumetric moisture content, θ, are unknown. Obviously, at least one other measurement and one other equation are required to solve for the two unknowns. To find this second equation, we exploit the fact that the dielectric "constant" is, in fact, a function of the applied electric field frequency.

3.2 Soil Test Programs

There were two types of test programs conducted, laboratory and controlled field testing. The laboratory tests were conducted to secure data with different soils having varying moisture and compaction levels and using reconstituted soil at different gradation levels.

The soil testing was conducted on a soil with variable compactions at constant moisture. These compaction tests were completed in a wooden frame structure 6' x 6' x 1.25'. Soil was moisturized with de-ionized water, mixed and allowed to stand for 12 hours to fully equilibrate. The moisture level was determined by using the oven dry test procedure as specified by ASTM D 2216. The soil was then placed into the compaction frame and compacted using an electric Wacker vibratory compacter.

The vibratory compactor fit the frame such that each compaction level had four vibratory passes with no compactor overlap, thus ensuring each compaction level had the same compactive effort. For the next compaction level, the vibratory compactor was rotated 90 degrees and four vibratory passes were completed, again with no compactor overlap. In total, eight compactor passes for each of the five compaction levels were completed. The compaction pattern is shown in Figure 3-2.

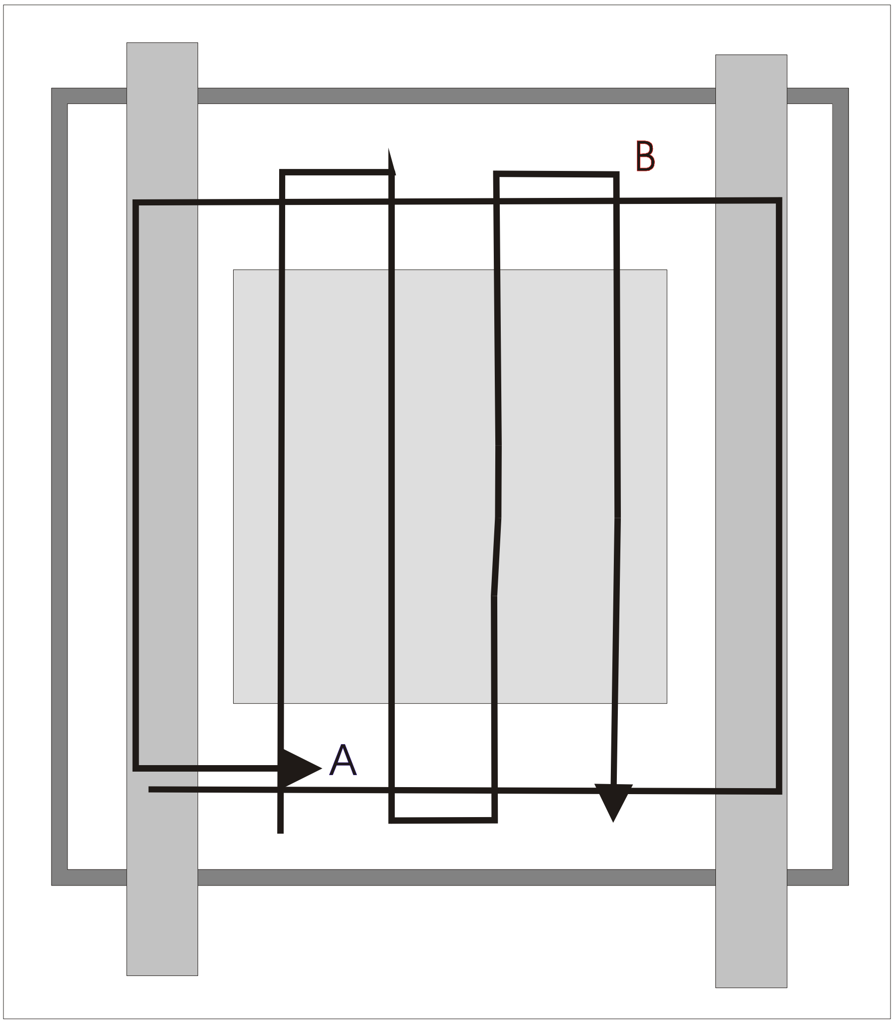


Figure 3-2. Vibratory Compactor Pattern for Compaction Tests

The density/compaction profile is seen in Figure 3-3, below. As can be seen, approximately 65% of the compaction is achieved after one compactor pass. The remaining 35% of the compaction is achieved with the additional compactor passes. Test data were taken on the uncompacted soil, but the data was not used due to the scattering of data from the instruments and the difficulty in having an appropriate surface on which either gauge could take data. Therefore, as shown in Figure 3-3, compaction levels of one, two, four and eight were selected for data,

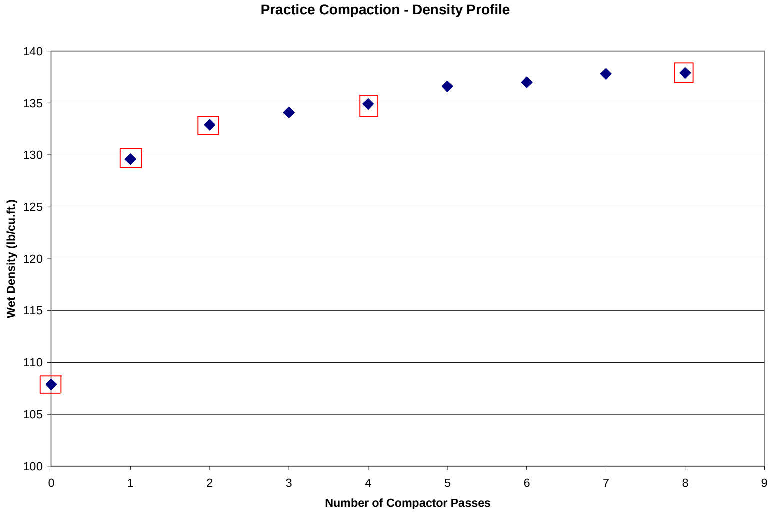


Figure 3-3. Density/Compaction Profile

It was determined that eight SDG measurements would be taken around the NDG sensor hole, as shown in Figure 3-4. For each of the SDG measurements, one NDG measurement would also be taken. While this is a time consuming method of collecting data, it is necessary for obtaining relevant and useful data, and proved very effective.

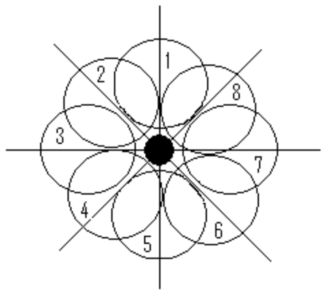


Figure 3-4. Measurement Pattern for the Calibration Compactions

Given the size of the frame, it was determined that four positions would be used to collect data on each of the five compaction levels. The four measurement positions, seen in Figure 3-5, labeled A, B, C and D were used to mark the center, around which each of the SQIs and the NDG would take measurements. The NDG was used in direct transmission mode with its rod at a depth of four inches. Each of the five SDG units took a total of eight measurements around each of the four positions. As a result, a total of 32 measurements were taken on each of the compaction levels with each unit. Within each moisture level, five compaction levels were completed; thus, 160 measurements were taken at each moisture level with each unit. Therefore, with five moisture levels, each individual unit took a total of 800 measurements.

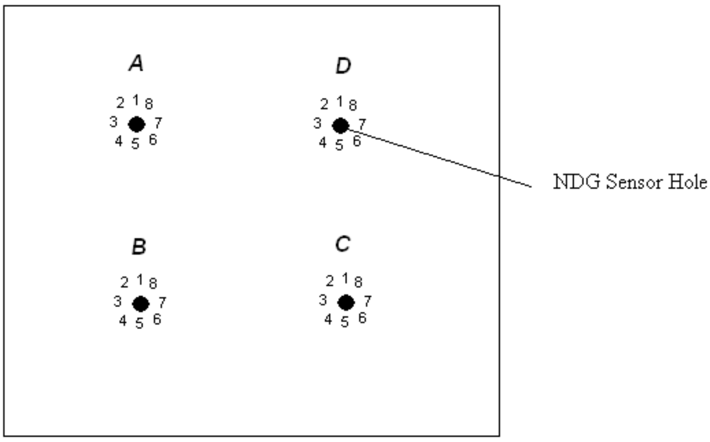


Figure 3-5. Sensor Hole Placement in Frame

Both a Proctor test (ASTM D 698) and a sieve analysis (ASTM C 136) were completed on the material used in the practice/preliminary compaction and the material to be used in the five calibration compactions.

To illustrate the selection of moisture levels, the Proctor peak for the material used in the one test compaction occurred at 128 lb/ft^3 and 8.25% moisture. Based upon the optimum moisture content for the calibration material, 8.25%, and the associated maximum dry density, 128 lb/ft^3, as determined from the Proctor test, five target test moisture values were determined: 5%, 6.5%, 7.5%, 8.5% and 9.5%. The five moisture levels spanned the working range for the material and each was used with five different compaction levels. Each moisture level was prepared using a pre-calculated amount of de-ionized water that was mixed into soil and allowed to equilibrate at least overnight. A calibrated NDG was used to determine the wet density of the compaction levels and oven drying of several small samples before the compaction and after the compaction was used to determine the gravimetric moisture content in accordance with ASTM D 2216.

Figure 3-6. Compaction of Test Soil

For this task, the five calibration compactions were completed, each at a different moisture level. Each of the compactions had five compaction levels and data was collected using a NDG and four SQIs. Figure 3-6 shows the use of the vibratory compactor on the test soil.

Figure 3-7. Taking Data with a SQI and a NDG

Figure 3-7 shows data being taken with a SQI and a NDG on a test compaction. It was necessary for great care and control to be taken during these compactions in order to ensure overall SQI data workability and reliability in algorithm development.

Oven dry results were used as the percent gravimetric moisture standard and the NDG was used as the wet density standard for the five calibration compactions. From the oven dries and NDG wet densities, the achieved dry densities were calculated.

For the calibration compactions, great care was taken to achieve the targeted moisture levels. During the drying or moisturizing process of the soil, oven dries were completed to monitor the process. On the morning of each compaction, oven dries were completed to determine the starting percent gravimetric moisture. Then, at the end of each compaction day, soil samples were taken from each of the four positions and oven dries were completed, calculating the gravimetric percent moisture. The oven dry results from the end of the day and their computed standard deviations are in Table 3-1, below. The results from the morning oven dries, in increasing moisture order, were: 4.87%, 6.51%, 7.57%, 8.74% and 9.31%. Therefore, four out of five oven dries completed in the morning before the compaction were within one standard deviation of the oven dries completed after the compactions.

Position A (%)	**Position B (%)**	**Position C (%)**	**Position D (%)**	**Average (%)**	**Standard Deviation**
5.33	5.24	4.72	4.96	*5.06*	0.2774
6.69	6.18	6.55	6.29	*6.43*	0.2339
7.37	7.59	7.25	7.52	*7.43*	0.1524
8.37	8.40	8.71	8.64	*8.53*	0.1703
9.58	9.22	9.11	8.98	*9.22*	0.2577

Table 3-1. Oven Dry Results (After Compaction) and Standard Deviation

Table 3-2, below, details the average of the eight NDG wet density measurements around each of the four measurement positions (A, B, C and D), for each of the five compaction levels (0, 1, 2, 4 and 8). The average percent moistures calculated in Table 3-1 are used to distinguish between the five columns of averaged wet densities, as measured by the NDG.

Oven Dry Moisture (%)			**5.06**	**6.43**	**7.43**	**8.53**	**9.22**
NDG Wet Density (lb/ft^3)	**0**	A	101.8	108.1	105.2	113.6	119.0
		B	100.4	106.1	103.4	112.8	115.4
		C	99.5	103.3	102.7	114.9	114.5

# of Compactor Passes		D	100.9	103.4	108.0	119.7	123.0
	1	A	115.0	118.4	123.7	127.7	133.9
		B	115.3	119.5	123.2	127.8	131.2
		C	114.7	119.1	122.1	130.8	130.1
		D	116.9	120.5	122.8	132.0	135.0
	2	A	118.0	123.5	125.2	129.5	137.0
		B	118.6	122.5	124.8	127.7	133.9
		C	117.0	124.1	126.0	134.0	132.8
		D	119.5	123.6	125.9	133.0	137.1
	4	A	121.7	127.2	128.0	132.5	128.6
		B	121.4	126.2	129.7	131.5	135.4
		C	118.7	127.7	128.9	136.4	135.0
		D	122.0	126.5	128.3	135.4	138.9
	8	A	124.8	130.7	132.4	135.2	139.7
		B	123.2	129.0	132.8	134.0	136.9
		C	122.8	130.4	132.1	138.1	136.6
		D	123.7	130.0	132.8	138.2	138.7

Table 3-2. Average of 8 NDG Wet Densities Around the Sensor Hole

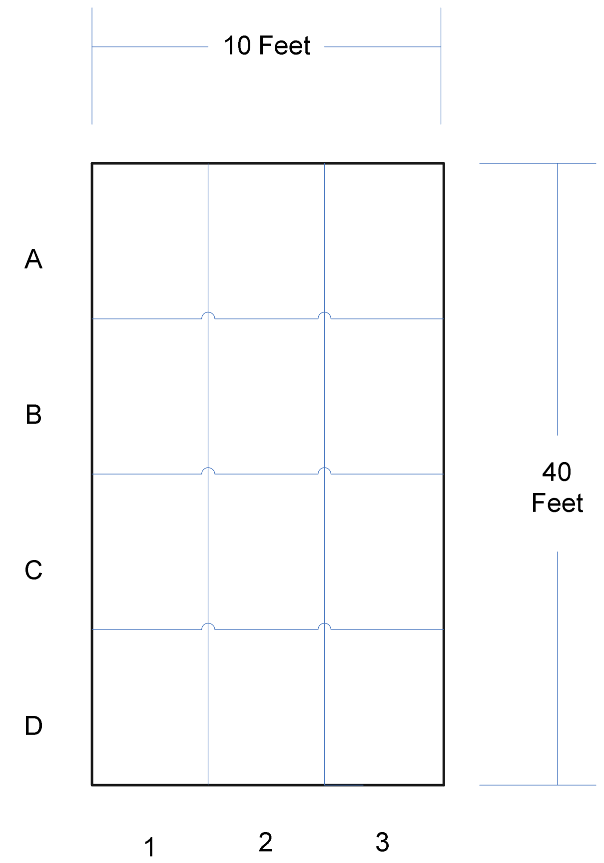


Figure 3-8. Test Area Designations on the Test Soil

From Table 3-2, when comparing the average of eight NDG wet density measurements around each position, it can be seen that with an increase in compactor passes, for each of the five moisture levels, the average wet density also increases at each of the four positions (A, B, C & D). As expected, much of the compaction, approximately 65%, is achieved with the first compactor pass. The remaining 35% of the compaction is achieved with the additional compactor passes.

A conclusion that can be drawn from the above oven dry and NDG wet density analysis is that the completed compactions had consistent moisture levels during the compaction days and uniform density around each position. As a result, possible errors created from the soil mixing/preparation and compaction process could be ruled out if any spectral anomalies arose during the investigation, as the SQI data analysis progressed.

With this stage of the lab testing completed, the testing moved to controlled field testing. The directions and procedures that were followed during the field tests are presented in Appendix A.

During this field test program to evaluate soil density gauges, TransTech secured data with a variety of Nuclear Density Gauges (NDG) on eight different soil types at various levels of compaction. The test program was conducted at locations in New York, Georgia, Oklahoma, Texas, and Washington. The tests were conducted by placing a 12-inch layer of the various types of soil over 10-foot by 40-foot area. This area was typically divided into 12 test areas as shown in Figure 3-8, above. The NDG rod hole was located in approximately the center of each test area. The test pattern for the NDG in each area is shown in Figure 3-9. Four readings were taken about a fixed rod hole location.

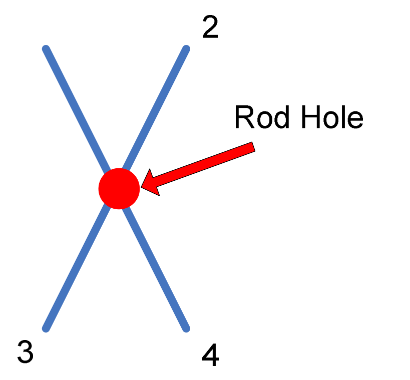


Figure 3-9. NDG Test Pattern

A total of nine NDG units from three manufactures were used in the testing. The NDG units were owned by five different organizations and operated by personnel from the owner organization. The NDGs used in this study included: 1) CPN MC-3; 2) Troxler 75-5594 (Serial Number 23531); 3) MD10506170; 4) Troxler 3450 (Serial Number 1013); 5) Troxler (Serial Number 38379); 6) Troxler (Serial Number 39576); 7) Humboldt 5001-EZ (Serial Number 2523); 8) Humboldt 5001 (Serial Number 102); and 9) Troxler (Serial Number 6964).

The test procedure called for having the soil rough graded and then compacted with a vibrating roller. The equipment was provided by the quarry operator. Data were taken at three or four compaction levels depending on the soil type. Data were taken after one pass of the roller and then after a number of passes until the soil was fully compacted. The number of passes is noted in the data tables below.

Figure 3-10. Data Being Taken During a Controlled Field Test in Washington

Figure 3-10 shows the data being taken in Washington.

The soils and type of testing that was performed are presented below in Table 3-3. The soil classifications are specified according to ASTM D 2487 – Standard Practice for the Classification of Soils for Engineering Purposes (Unified Soil Classification System).

The data from these tests are presented in Appendices B, C and D.

Also, during these tests, data were taken for an ASTM precision and bias statement. The test procedures and results are presented in Appendix E.

ASTM Designation	Common Designation	Soil Source	Test Location	Test Type
SW	Well graded sand with silt	Callanan, Halfmoon, NY	TransTech	Compaction Task 3 (completed)
SW (varied CC)	Well graded sand with silt	Callanan, Halfmoon, NY	TransTech	Gradation Task 7 (completed)
GP-GM	Poorly graded gravel with silt & sand	LaFarge North America, Buffalo, NY	TransTech	Compaction Task 8 (completed)
GP-GM, GW, GW-GM, & SW	Poorly graded gravel with silt & sand, Well-graded gravel with sand, Well-graded gravel with silt & sand & Well-graded sand with silt	LaFarge North America, Buffalo, NY	TransTech	Gradation Task 7 (completed)
ML	Brown sandy silt	LaFarge North America, Buffalo, NY	TransTech	Gradation Task 7 (completed)
GP-GM	Poorly graded gravel with silt & sand	Callanan, Pattersonville, NY	Callanan. Pattersonville, NY	Controlled Field Test Task 14 (November 2007)
SP	Sand with gravel	Callanan, Wynantskill, NY	Callanan, Wynantskill, NY	Controlled Field Test Task 14 (November 2007)
GP-GM	Gray 1¼” crushed CSBC	ICON Materials, Seattle, WA	ICON Materials, Seattle, WA	Controlled Field Test Task 20 (January 2008)
SP	-4” Gravel Borrow	ICON Materials, Seattle, WA	ICON Materials, Seattle, WA	Controlled Field Test Task 20 (January 2008)
GP-GM	Poorly graded gravel with sand and silt	Qore Properties, Atlanta, GA	Qore Properties, Atlanta, GA	Controlled Field Test Task 20 (February 2008)
SM	Georgia Red Clay	Qore Properties, Atlanta, GA	Qore Properties, Atlanta, GA	Controlled Field Test Task 20 (February 2008)
GP-GM	Crushed stone sub-base	Martin Marietta, Dallas, TX	Martin Marietta, Dallas, TX	Controlled Field Test Task 20 (March 2008)
CM	Sandy Clay	Clough Harbour, Dallas, TX	Clough Harbour, Dallas, TX	Controlled Field Test Task 20 (March 2008)

Table 3-3. Summary of Soil Testing

3-3 Development of Soil Properties Algorithm

The objective was to develop an algorithm to convert the complex impedance spectra into soil properties by identifying those features and feature processing methods that provide the most information about density and moisture. Spectral features can be found using several processing techniques. In this case, curve fitting and statistical analyses were performed on the data to locate and identify wet density and moisture features.

The presentation in this section discusses the general approach but does not discuss the actual algorithms that were developed and implemented as this is considered proprietary information and is key to the functionality of the final version of the SDG. Data taken in Phase I and early in Phase II are used to provide an illustration of the process. The application of the final algorithms to actual field data with the later versions of the hardware is presented in Appendices B, C, and E.

All data used in the following analysis were obtained during laboratory testing.

From previous work, it was observed that in a contacting mode, the SDG Model 1 is sensitive to surface irregularities. Therefore, during the Phase I program, measurements were taken with two contacting and two non-contacting units. The advantages and disadvantages of the non-contacting SDG unit were thoroughly investigated. *The completed curve fitting analysis showed that the non-contacting SDG can distinguish a change in signal based on a change in compaction level and moisture level. The data from the non-contacting units were more consistent than those from the contacting units. Therefore, all subsequent work and unit designs in the remainder of Phase I and all of Phase II dealt with a non-contacting SDG.*

Figures 3-11 and 3-12, below, show a typical magnitude/phase plot and real/imaginary plot, respectively, at one moisture level and five compaction levels (0, 1, 2, 4 and 8 Compactor

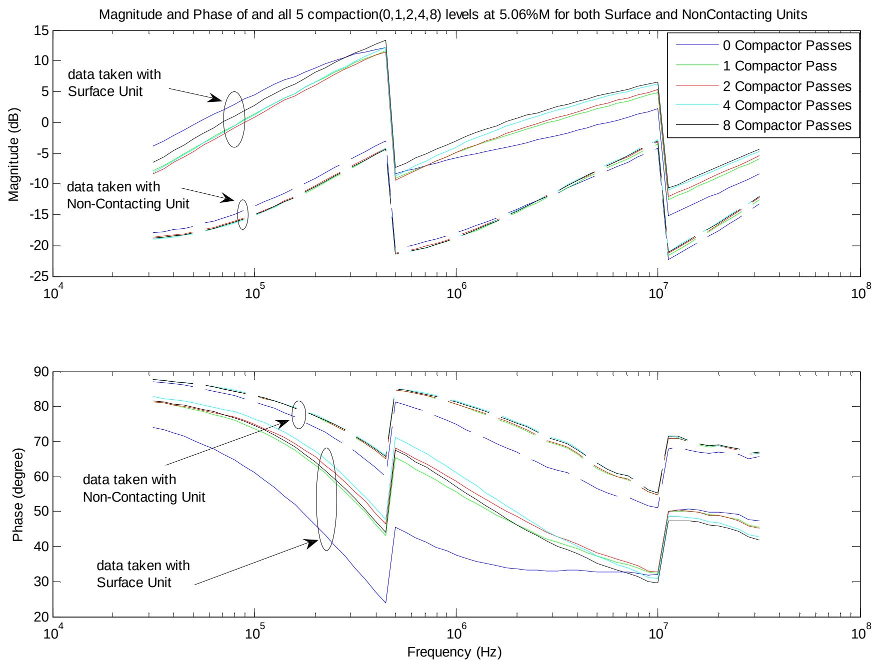


Figure 3-11. Magnitude and Phase versus Frequency for Contacting and Non-Contacting SDG

Passes), taken with a Contacting Model 1 SDG Unit and a Non-Contacting Model 1 SDG Unit on soil. The solid lines represent data taken with a contacting unit, while the dashed lines represent data taken with a non-contacting unit. The five colors represent the five compaction levels. As can be seen in the figure, and is mentioned in the above paragraph, the non-contacting SDG has a lower signal level than the surface SDG unit and also has less visual signal separation between the five compaction level curves. While the non-contacting SDG appears to have a small, if any, variation between compaction levels, *the completed curve fitting analysis shows that the non-contacting SDG does distinguish a change in signal based on a change in the compaction level. Further, the data from the non-contacting unit had less variance than that of the contacting unit.* The breaks in the frequency spectrum seen at 500 kHz and again at 10 MHz are due to the sensor switching. The sense resistor switching is required to insure adequate performance of the unit over the large frequency range. As a result, the sense resistor regions are broken-up into three regions: low, mid and high frequency regions.

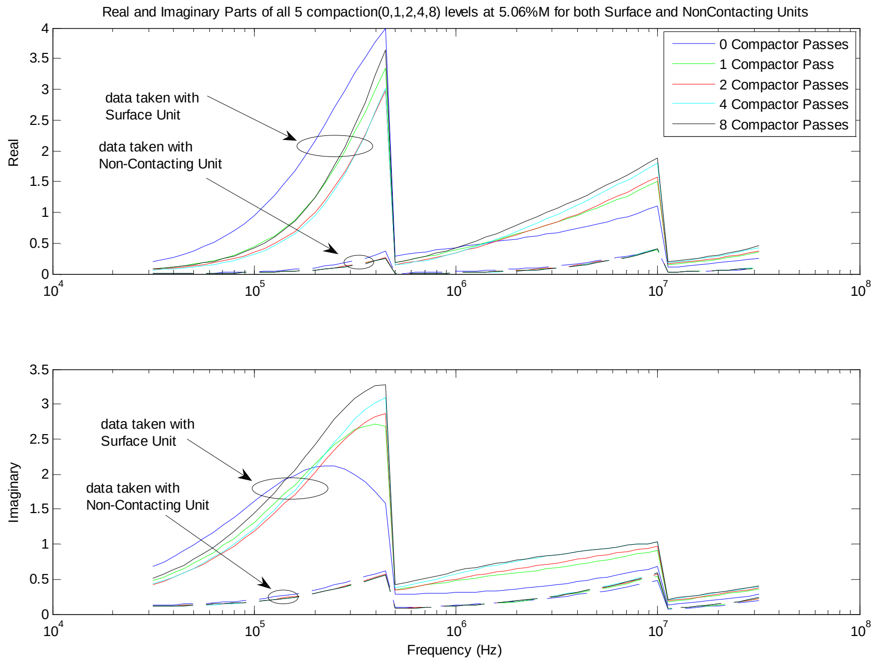


Figure 3-12. Real and Imaginary versus Frequency for Contacting and Non-Contacting SDG

A second order polynomial was used to characterize the SDG data sets at each compaction level (0, 1, 2, 4 and 8 Compactor Passes) and each moisture level (5.06%, 6.43%, 7.43%, 8.53% and 9.22%) in each of the three frequency regions for each of the four data representations (magnitude, phase, real and imaginary). A second order polynomial is given by

$$y = Ax^2 + Bx + C,$$

where A, B and C are the coefficients used to characterize the data. Next, linear fits were completed using the calculated second order polynomial coefficients and the measured nuclear density gauge (NDG) wet density through the five compaction levels for each of the four measurement positions (A, B,C and D) and for each of the five moisture levels (5.06%, 6.43%, 7.43%, 8.53% and 9.22%). If the linear fits of the coefficient versus NDG wet density around each of the four positions and for each of the five moisture levels were considered significant ($R^2 > 0.80$), then the coefficient may be significant in extracting the density information from the frequency spectrum and ultimately calculating wet density.

Using the curve fitting feature identification process outlined above, nine possible features were found to be significant. The identified curve fitting features from which it may be possible to calculate wet density, are listed in Table 3-4, below.

Non-Contacting SDG
1. Phase, frequency region one, *A* coefficient 2. Phase, frequency region two, *A* coefficient 3. Phase, frequency region two, *B* coefficient 4. Phase, frequency region two, *C* coefficient 5. Imaginary part, frequency region two, *A* coefficient 6. Imaginary part, frequency region two, *B* coefficient 7. Imaginary part, frequency region two, *C* coefficient 8. Imaginary part, frequency region three, *A* coefficient 9. Imaginary part, frequency region three, B coefficient

Table 3-4. Non-Contacting – Possible Wet Density Features

A careful analysis of the identified possible features above was necessary in order to determine each feature's ability to be used in the calculation of wet density and, equally as important, for use in the field (i.e., real world robustness). Some of the characteristics that were used to determine if an identified possible feature could be used in the calculation of wet density were: 1) the strength of the relationship between the SDG wet density feature and the measured NDG wet density, 2) the comparability of the standard deviations between the calculated SDG wet densities and the measured NDG wet densities and 3) the possible relationship between the SDG's wet density and moisture measurements.

A similar approach was used to identify possible moisture features. Before moisture features could be identified, the data was reorganized such that the wet density was held constant and moisture varied. Then, using the curve fitting feature identification process, three possible features were found to be significant. The identified moisture features from which it may be possible to identify a moisture relationship and calculate the moisture content are listed below.

Non-Contacting SDG – Possible Moisture Features:

1. Imaginary part, frequency region three, *A* coefficient
2. Imaginary part, frequency region three, *B* coefficient
3. Imaginary part, frequency region three, *C* coefficient

Each possible moisture feature was investigated and their level of dependence on density was determined. Since at this point in the program, the SDG wet density calculation is moisture dependent, it was important to find a moisture feature with repeatability.

Based upon this approach, two inversion models were developed, one for wet density and one for moisture.

Using the moisture inversion model, the moisture content was calculated for both SDG Model 1 units, SN1 and SN3, and reported in Tables 3-5 and 3-6, below. Since the SDG is designed to be used on compacted soil, the average (AVG) and standard deviation (STD) columns of Tables 3-5 and 3-6 were computed using the moisture calculations from one to eight compactor passes.

Oven Dry	Compactor Passes	A	B	C	D	AVG	STD
5.06	0	5.06	4.48	4.63	4.26		
	1	5.19	5.22	5.11	4.92	5.35	0.3465
	2	6.36	5.39	5.19	4.86		
	4	5.55	5.15	5.30	5.46		
	8	5.64	5.42	5.23	5.56		
6.43%	0	4.94	4.77	4.23	5.00		
	1	6.09	6.49	5.94	6.19	6.30	0.1939
	2	6.38	6.17	6.28	6.07		
	4	6.26	6.46	6.48	6.17		
	8	6.33	6.65	6.21	6.54		
7.43%	0	5.50	5.48	5.39	5.93		
	1	6.66	7.28	6.61	6.76	7.19	0.3541
	2	7.07	7.92	7.16	7.17		
	4	6.95	7.43	7.13	6.97		
	8	7.33	7.58	7.46	7.52		
8.53%	0	6.68	7.10	6.94	8.09		
	1	8.67	8.71	8.33	8.99	8.93	0.3464
	2	8.58	8.96	8.68	9.21		
	4	8.80	9.01	9.07	9.09		
	8	8.74	8.83	9.51	9.71		
9.22%	0	7.87	7.82	8.02	8.00		
	1	9.06	8.50	9.19	9.13	9.03	0.3124
	2	9.52	8.93	9.24	9.42		
	4	8.92	8.53	8.92	8.65		
	8	8.88	9.17	8.95	9.53		

Table 3-5. SDG Model 1 (SN1) Moisture

Oven Dry	**Compactor Passes**	**A**	**B**	**C**	**D**	**AVG**	**STD**
5.06	0	4.17	4.07	4.09	4.22		
	1	5.19	4.97	4.84	5.24	5.20	0.2339
	2	5.22	5.15	4.79	5.34		
	4	5.68	5.36	5.05	5.36		
	8	5.41	5.46	5.01	5.19		
6.43%	0	4.83	5.13	4.72	5.11		
	1	6.00	6.09	6.15	6.16	6.37	0.2485
	2	6.11	6.40	6.20	6.43		
	4	6.21	6.63	6.66	6.40		
	8	6.51	6.89	6.53	6.55		
7.43%	0	5.57	6.21	5.70	6.05		
	1	6.96	7.90	6.57	6.89	7.35	0.3946
	2	7.10	7.87	7.12	7.19		
	4	7.22	7.81	7.13	7.33		
	8	7.67	7.76	7.45	7.64		
8.53%	0	7.23	7.46	6.75	7.88		
	1	8.53	8.81	8.12	9.22	8.81	0.3029
	2	8.63	8.81	8.66	8.58		
	4	8.76	8.86	8.76	9.11		
	8	8.96	8.72	9.41	9.06		
9.22%	0	7.99	8.31	7.03	7.74		
	1	8.84	8.56	9.08	9.53	8.99	0.3869
	2	9.51	9.14	8.70	8.86		
	4	9.20	8.66	8.59	8.49		
	8	9.44	9.06	8.58	9.62		

Table 3-6. SDG Model 1 (SN3) Moisture

The agreement between the two SDGs' calculation of moisture and the standard (i.e., oven dry moisture results) were assessed. Table 3-7, below, is a summary of the agreement assessment between the SDGs and the standard. First, using the moisture results from one to eight compactor passes, each day's moisture average (Avg.) was computed. Then, the SDG's average moisture was subtracted from the average oven dry results. Next, the five differences between the SDG and the oven dry results were averaged. The average differences (Avg. Diff) between the SDG and the standard for the SDG Model 1 units, SN1 and SN3, were -0.03 and 0.05, respectively. Both SDGs' average differences were below the average standard deviation (Avg. STD) of the oven dry result, 0.22. *The conclusion was that the agreement between the SDGs' moisture calculation and the standard oven dry moisture results was high.*

A second test performed on the moisture data was the calculation of the correlation and p-value between the SDG and the standard oven dry moisture results, shown in Table 3-8. *The correlation for each non-contacting SDG was high (i.e., greater than 0.90) and the corresponding p-values were found to be less than 0.05; therefore, the correlations between the oven dry moisture results and the SDG moisture calculations are significant.*

	Avg. Oven Dry	Avg. SDG SN1	Diff (Oven-SN1)	Avg. SDG SN3	Diff (Oven-SN3)
	5.06	5.35	-0.29	5.20	0.14
	6.43	6.30	0.13	6.37	0.06
	7.43	7.19	0.24	7.35	0.08
	8.53	8.93	-0.40	8.81	-0.28
	9.22	9.03	0.19	8.99	0.23
Avg. STD	**0.22**	**0.31**		**0.31**	
Avg. Diff			***-0.03***		***0.05***

Table 3-7. Moisture Agreement Assessment Between Standard (Oven Dry) and SDG Model 1 (SN1 & SN3)

	Oven Dry and SDG SN1	Oven Dry and SDG SN3
Correlation	0.9839	0.9928
p-value	0.0025	0.0007

Table 3-8. Correlation and p-values Between Oven Dry Results and SDG Measurements

Using the above moisture and wet density inversion methods for the SDG, the wet densities for the five compaction calibrations were calculated for both SDG Model 1 units, SN1 and SN3, and are shown in Tables 3-9 and 3-10.

Oven Dry	Compactor Passes	A	B	C	D
5.06	0	98.10	98.07	99.71	102.15
	1	115.33	112.94	115.50	114.67
	2	113.28	118.11	118.93	119.24
	4	123.01	122.75	121.17	121.70
	8	122.50	121.85	122.94	121.51
6.43%	0	105.93	97.95	90.60	101.05
	1	118.92	115.98	118.31	117.99
	2	121.27	122.07	120.83	122.36
	4	124.72	124.16	122.79	124.07
	8	126.60	124.94	126.78	125.80
7.43%	0	107.00	95.64	90.25	106.10
	1	128.51	128.12	129.05	127.94
	2	130.16	127.54	130.89	130.26
	4	132.78	133.64	132.01	132.82
	8	135.13	134.93	132.78	133.02
8.53%	0	110.19	113.57	117.23	119.40
	1	129.40	128.90	130.98	132.04
	2	131.33	130.23	132.87	130.51
	4	132.77	131.81	132.53	133.29
	8	134.93	132.64	133.79	131.63
9.22%	0	121.90	107.62	115.14	124.93
	1	131.78	132.52	131.32	133.03
	2	135.85	135.35	134.35	132.80
	4	137.96	137.02	135.56	136.11
	8	140.61	137.28	135.82	136.67

Table 3-9: SDG Model 1 (SN1) Wet Density

Oven Dry	Compactor Passes	A	B	C	D
5.06	0	103.96	99.18	103.78	101.02
	1	115.30	114.58	119.53	113.66
	2	117.32	118.92	122.09	118.99
	4	122.42	121.16	123.80	122.11
	8	121.70	120.71	124.54	122.36
6.43%	0	111.23	105.61	98.89	106.10
	1	118.61	117.78	117.81	119.14
	2	122.84	121.04	121.15	122.54
	4	124.89	122.75	121.95	124.42
	8	125.95	123.60	125.52	126.60
7.43%	0	110.58	105.98	105.48	110.63
	1	126.69	122.76	129.41	128.57
	2	129.10	126.29	129.79	129.26
	4	130.64	130.39	131.45	130.98
	8	133.35	133.05	133.13	132.49
8.53%	0	118.83	122.54	119.43	118.54
	1	130.30	129.85	131.30	131.69
	2	132.75	131.00	132.66	132.88
	4	132.96	131.93	133.86	132.71
	8	134.01	132.97	133.70	134.92
9.22%	0	121.75	110.40	118.74	126.48
	1	134.74	133.92	134.06	133.57
	2	134.77	134.96	137.27	135.72
	4	136.33	136.34	137.49	137.08
	8	137.72	137.15	137.61	136.62

Table 3-10: SDG Model 1 (SN3) Wet Density

The agreement between the two SDGs' calculations of wet density and the standard (i.e., NDG) were assessed. Table 3-11, below, is a summary of the agreement assessment between the non-contacting SDGs and the standard. First, the difference between the standard NDG and the SDG wet density was taken. Then, the daily average of the difference was reported. Next, the average difference of all five days was computed and the wet density agreement between the SDG and the standard NDG for the twenty compaction levels and five moisture levels for SDG SN1 and SN3 was 0.12 lb/ft^3 and -0.03 lb/ft^3, respectively. The average wet density standard deviation (STD) for the completed compactions was 1.36 lb/ft^3 for the NDG, 1.14 lb/ft^3 for SDG SN1 and 1.15 lb/ft^3 for SDG SN3. *The conclusion was that the agreement between the non-contacting SDGs' wet density calculation and the standard NDG wet density measurements was high.*

A second test performed on the wet density data was the calculation of the correlation and p-value between the non-contacting SDG and the standard NDG wet density measurements, the results of which are shown in Table 3-12. A correlation and p-value were computed for each day of compaction (i.e., each day was a different moisture level*). The correlation for each SDG was high (i.e., greater than 0.90) and the corresponding p-values were found to be less than 0.05; therefore, the correlations between the NDG wet density measurements and the non-contacting SDG wet density calculations are significant.*

	Avg. NDG	Avg. Diff (NDG – SDG SN1)	Avg. Diff (NDG - SDG SN3)
Day 1 – 7.43%		-3.79	-2.40
Day 2 – 6.43%		2.58	2.64
Day 3 – 5.06%		0.49	-0.37
Day 4 – 9.22%		0.43	-0.28
Day 5 – 8.53%		0.87	0.26
Avg. STD	**1.36**	**1.14**	**1.15**
Avg. Diff		***0.12***	***-0.03***

Table 3-11. Wet Density Agreement Assessment Between Standard (NDG) and SDG Model 1 (SN1 & SN3)

Moisture Level	NDG to SDG SN1	NDG to SDG SN3
5.06%	Corr = 0.9748 p-value = 0.0000	Corr = 0.9506 p-value = 0.0000
6.43%	Corr = 0.9668 p-value = 0.0000	Corr = 0.9696 p-value = 0.0000
7.43%	Corr = 0.9664 p-value = 0.0000	Corr = 0.9799 p-value = 0.0000
8.53%	Corr = 0.9526 p-value = 0.0000	Corr = 0.9417 p-value = 0.0000
9.22%	Corr = 0.9516 p-value = 0.0000	Corr = 0.9399 p-value = 0.0000

Table 3-12. Correlation and p-values Between NDG and SDG Measurements

After the non-contacting SDG algorithms were developed for moisture and wet density, an additional compaction test was completed. The average wet density results from zero compaction passes to eight compaction passes for two SDG units and two NDG units are reported in Table 3-13, below. The instruments performed as expected, with wet density measurements increasing with the number of vibratory compaction passes. The standard deviations (STD) of the SDG were as expected for un-calibrated prototype units.

The correlations, shown in Table 3-14, for all four unit comparisons above were high (i.e., greater than 0.90) and the corresponding p-values were all calculated to be less than 0.05; *therefore, the correlations between the NDG wet density measurements and the non-contacting SDG wet density calculations are significant.*

This compaction test was completed at one moisture level, having an average oven dry result of 7.72% moisture. The average non-contacting SDG moisture results were 8.08% and the average NDG moisture results were 6.91%.

Compactor Passes	NDG (1) lb/ft3	NDG (2) lb/ft3	SDG (SN 1) lb/ft3	SDG (SN 2) lb/ft3
0	104.01	108.10	97.91	92.3
1	121.09	128.85	121.94	121.85
2	126.26	128.23	126.38	126.01
4	128.38	130.98	127.97	130.35
8	133.08	135.50	131.35	132.29
STD	1.41	1.20	0.92	2.54

Table 3-13. Additional Compaction Wet Density and Standard Deviation Results

	Correlation	p-value
NDG (1) to NDG (2)	0.9781	0.0039
NDG (1) to SDG (SN 1)	0.9903	0.0011
NDG (1) to SDG (SN 2)	0.9869	0.0018
SDG (SN 1) to SDG (SN 2)	0.9983	0.0001

Table 3-14. Additional Compaction Correlation and p-value Results

As the program progressed through Phase II, the algorithms were further developed based upon the data acquired during Phase II. The final form of the algorithms has been improved and is installed in the current versions of the test units as well as the production unit. The final form of these algorithms is not provided as it is being treated as proprietary information and a trade secret as part of the effort to commercialize the technology.

4.0 COMMERCIALIZATION EFFORTS

The technical progress in the development of a Non-Nuclear Soil Density Gauge serves only part of the objectives of DHS and TransTech. A technical success without a market success does not serve anyone's interests. DHS DNDO's mission to eliminate access to minimally controlled radiological devices through the development of alternative technology can be achieved by having the new non-nuclear technology displace the existing nuclear products. TransTech's objective is to produce and sell new non-nuclear products.

As part of the effort to commercialize the SDG, TransTech has been working to develop an ASTM standard covering its use. TransTech initiated efforts to secure an ASTM standard for the SDG in mid-2005. This effort is ongoing. TransTech learned in the product introduction of the Pavement Quality Indicator (PQI) the importance of having a standard governing its use by an appropriate standard agency and the time required to secure such a standard. Therefore, the effort to secure the standard for the SDG was initiated early in its development. The current status is that a revised draft standard (See Appendix F for the current draft of the standard) is being submitted to a vote for acceptance by the cognizant ASTM subcommittee in 2009. There was a request for additional changes and data, which were secured as part of the Phase II program.

Once the ASTM standard for the SDG is ready for the final approval, efforts will be initiated to secure standards in countries which are primary targets for product sales. TransTech will work primarily through their international distributor in each country.

There is a requirement that instruments sold in Europe and other international markets be certified to meet the various directives of the European Union. The securing of certification under these directives permits the product to carry the CE Mark (see Figure 4-1).

Figure 4-1. The CE Logo Mark

The specific directives that the gauges will require are: EN 61326-1 IAW CISPR 11; EN 61326-1 IAW EN 61000-4-2; EN 61326-1 IAW EN 61000-4-3; EN 61326-1IAW EN 61000-4-8; and IAW EN 61010-1. Based on past experience, there will be two certification tests required in order for the production version of the SDG to be sold internationally. It is typical that the first certification test identifies a design shortcoming that will need to be modified in order to have the unit pass the testing. The modified unit will have to be re-tested.

The thirty SDG Model 100A units fabricated in Task 19 of Phase II are being used as part of a Beta Test Program. Five of the units will be retained by TransTech for continued testing and development.

Some of these Beta Units have been loaned to preferred testers as follows:

1. NYS DOT,
2. KeySpan (National Grid)/PS&S LLC,
3. Texas Transportation Institute at Texas A&M,
4. Hillis Carnes Engineering in Maryland.
5. US Army Corps of Engineers, ERDC WES,
6. Kentucky Transportation Center,
7. Pennsylvania State University,
8. Highway Construction Inspection Ontario.

The unit at ERDC WES is scheduled to go to Afghanistan, since the Army Corps of Engineers has extreme difficulty in shipping any nuclear based device overseas. The unit for the Kentucky Transportation Center went out in August to be part of a two year soil gauge evaluation program funded by the Kentucky DOT. The unit at Penn State's Crop and Soil Science Department will ship in the next two weeks and be used to measure density in un-compacted materials with about 5% organic material. They are looking for a practical replacement for the nuclear gauge. Agricultural applications for measuring soil density include predicting irrigation and drainage patterns, fertilizer/nutrient delivery, and plant root development. The SDG was not designed for agriculture uses. Therefore, the ability to use it for agriculture applications will significantly increase its ability to fully replace the NDG.

Two units have been placed with TransTech sales representatives in North Carolina and Texas. An additional unit will go to KeySpan Energy (now National Grid) as part of an agreement for their support on the original program.

The balance will go, or have gone, to commercial customers who have agreed to provide results from their normal testing.

The Beta Testers have been provided a developmental SDG Model 100A unit (see Figure 2-4), an operator's manual (see Appendix G), a Beta Testing protocol and unlimited phone support. They will also receive any hardware and/or software updates to keep the unit comparable to the then current commercial offerings for a period of two years. They are asked to provide feedback on the user interface and the operation of the unit. As part of the operational feedback, TransTech hopes that the Beta Tester will provide soil characteristics, nuclear gauge readings, and a SDG data file for any readings that appear anomalous. It is expected that there will be soil variations that have not been accounted for. The data provided would help extend the range of applicability of the unit.

While TransTech realistically expects limited data from the Beta Testers, the placing of units in the hands of customers has the advantage of securing user inputs on the user interface, the data they want to see or are required to provide to the regulatory agency, and comments on its usability, as well as helping to create a "buzz" t will help to springboard its commercialization. The key information that is being sought during the Beta Testing is the suitability of the user interface.

Testing will continue after the completion of the formal DHS Phase II program.

A listing of all the units and their status is presented in Table 4-1, below.

Other units will be shipped later to the following:

- Roadware (Netherlands Distributor)
- Engius (3 units, US Distributor for Western US)
- Milestone (End Customer)
- Levy Group (End Customer)
- NTS Europe SRI (Italian Distributor)

Thus far, the Beta Testers have provided some good data, but it has not been as extensive as hoped for. They have also identified a number of operational issues in the user interface. These will be corrected and incorporated into the production units and into updates for the current Beta Units.

The production version of the SDG is shown in Figure 2-5. TransTech has presented the SDG at major trade shows in the United States as well as in China and Russia. A sales brochure for US sales has been prepared (see Appendix H) and distributed. TransTech's distributor in China, Earth Products China, has prepared a sales brochure (see Appendix I) that features the SDG for use in trade shows in China and for sales support.

TransTech is committed to bringing this technology, as well as product enhancements, to market.

Unit #	User Name:
B1	TSI. Software Development
B2	Production - Not Finished
B3	TSI Sales Rep North Carolina
B4	Highway Construction Insp., Ontario
B5	BAV CONEXPO Russian Translation
B6	TSI Sales Bangkok
B7	Taisei, India
B8	TSI Sales Rep Texas
B9	KeySpan, New Jersey
B10	Hillis - Carnes Engineering, Maryland
B11	Penn State University
B12	TTS Europe
B13	EPC, China
B14	Wolverine Tractor, Michigan
B15	TSI Sales Bangkok
B16	OPTEC, South Africa
B17	Cornell Construction, Oklahoma
B18	TSI R&D
B19	Proeti, Spain
B20	NYS DOT
B21	UKY J Fisher
B22	ABUS Ingvald, Norway
B23	Rieth Riley, Indiana
B24	Global Road Equipment, Australia
B25	TSI R&D
B26	TSI – Not Assigned
B27	TSI R&D
B28	USACE/WES
B29	Production - Not Finished
B30	Production - Not Finished

Table 4-1. Status of Beta Units

5.0 CONCLUSIONS

The DHS program built on four years of development work that was funded by a consortium of NYSERDA, Northeast Gas Association, Consolidated Edison, and KeySpan (now National Grid), plus a significant commitment of TransTech's own resources. This work resulted in the development through three generations of a gauge that could reliably and accurately generate and record the complex impedance spectra of soil samples. It also demonstrated that information as to the density and moisture levels of the soil could be extracted from the complex impedance spectra.

During Phase I of the program, TransTech demonstrated that using the hardware from the previous work, soil density and moisture could be determined on a typical soil found in construction. The objects of Phase II were to extend the development of the hardware to a pre-production level and use this hardware to extend the demonstrated applicability of the gauge to different soil classification and in different geographic locations.

TransTech has accomplished the technical objectives of the program and has also moved the gauge toward commercial production. This will now provide the user with the choice of two non-nuclear gauges for the evaluation of asphalt and of soils.

TransTech plans on moving to the next step to combine both functions in a single gauge which will provide a complete suite of non-nuclear density gauges for asphalt only, soil only and asphalt and soil combined.

6.0 REFERENCES

1. Hilhorst, M. A. (1998), "Dielectric Characterization of Soil," Wageningen, Netherlands.
2. Topp, G.C., Davis, J.L., and Annan, A.P., “Electromagnetic Determination of Soil Water Content,” Water Resources Research, 16(3): 574-582, 1980.
3. Roth, K., Schulin, R., Fluhler, H., and Attinger, W., “Calibration of Time Domain Reflectometry for Water Content Measurement Using a Composite Dielectric Approach,” Water Resources Research, 26(10): 2267-2273, 1990.
4. Rinaldi V., et. al., “Impedance Analysis of Soil Dielectric Dispersion (1 MHz – 1 GHz)”, Journal of Geotechnical & Geoenvironmental Science, Vol. 125, No.2, 1999
5. Hilhorst, M. A. and Dirkson, C. (1994), "Dielectric Water Content Sensors: Time Domain Versus Frequency Domain," Symposium and Workshop on Time domain Reflectometry.
6. Drnevich, V.P., et al, Real-Time Determination of Soil Type, Water Content, and Density Using Electromagnetics, FHWA/IN/JHRP-2000/20, Purdue University School of Civil Engineering, Indiana Dept. of Transportation, Purdue University, West Lafayette, IN, August 17, 2001.

Appendix A. Controlled Field Test Procedures

Appendix B. SDG Controlled Field Test Density Data Analysis and Summary

Appendix C. SDG Controlled Field Test Moisture Data Analysis and Summary

Appendix D. NDG Controlled Field Testing Procedures and Results

Appendix E. SDG Controlled Field Precision Test Procedure and Results

Appendix F. SDG Draft ASTM Standard

Appendix G. SDG User Manual

Appendix H. TransTech SDG Sales Brochure (Front Page Only)

Appendix I. Earth Products China Sales Brochure Featuring the SDG (Front Page Only)

APPENDIX A

Controlled Field Test Procedures

Appendix A. TransTech Systems Soil Density Gauge (SDG) –Testing Protocol

Project History

The Soil Density Gauge (SDG) prototype units are scheduled to begin field testing in New York State in early September 2007 and in other States in early December 2007. TransTech Systems is under contract to the Department of Homeland Security (DHS) to develop a non-nuclear soil density and moisture gauge. The current objective of the program is to use prototype units, which were developed under funding from DHS, New York State Energy and Research Development Authority (NYSERDA), Keyspan Energy, ConEd and TransTech Systems, Inc., to collect data on the wide variety of soil types and mineralogies that are used on construction sites throughout the U.S. This will verify the ability of our technology approach of using electromagnetic impedance spectroscopy to function as well as the current industry standard, the Nuclear Density Gauge (NDG).

Currently, the unit has been verified to be equivalent to the NDG on two soil types secured from suppliers in New York State, an SW – well-graded sand and a GP-GM – poorly graded gravel with silt and sand. At this time, we are working with the second calibration, GP-GM material, to continue our gradation testing. It is expected that this gradation testing will allow for a better understanding of any field calibration, based on gradation, that may be necessary. While the unit is only calibrated to read moisture and density for these specific soil types in our laboratory, the field unit's readings (i.e., coefficient values) are expected to show an increase for density and/or moisture with increasing compaction for any of the soils being tested.

As we proceed with the massive amount of data collection we have planned for NYS and locations in other states, we will continue to fine tune the instrument and its algorithms, as well as develop a quick and easy field calibration procedure, so that at the end of the DHS Phase II program in August 2008, we will be ready to introduce the finished product.

We feel it is important to test not only on different soil types/gradations, but on ones with different mineralogies as well, hence our desire for the geographically spread-out testing. Working together, we intend to develop an easier and faster soil testing instrument!

Soil Calibration

This unit has only been verified to work on two materials, an SW soil and a GP-GM soil. Currently, the unit has algorithms to convert the electromagnetic impedance readings to provide wet density and moisture values on GP-GM material. While the SDG unit will measure and collect data on material that is not classified as GP-GM, algorithms have not been verified to provide accurate wet density and moisture levels. The output presented on the display of the prototype units provided for field-testing will be data coefficient values interpreted from the information taken from the soil spectrum. The output results will be proportional to the nuclear density gauge (NDG), which is the industry accepted method to measure wet density, meaning that the SDG's outputs will increase/decrease when the NDG's wet density outputs increase/decrease, within the accepted standard error of each device. At this stage of the unit's development, we certainly **do not** expect it to provide accurate readings of density/moisture equivalent to a nuclear density gauge or other standards (sand cone, etc.) on any soil that it has not been calibrated on. The data that is collected during the field-testing will be used to develop the algorithms necessary to enable it to provide accurate density and moisture readings when the product release occurs in mid-to-late 2008.

We have found during our research that gradation of the material under test is important in adjusting the wet density and moisture algorithms. For this reason, we ask that you not only provide the gradation information of any material you test the instrument on, but that you provide the Proctor information as well.

For each of the materials that you test the SDG unit on, we ask that you provide as many of the following as possible:

1. the Sieve Analysis Report,
2. the Proctor Test Report,
3. the NDG wet density and moisture readings (see below),
4. secondary moisture measurements from the material tested in the field, such as oven dry result, Moisture Meter, etc., and,
5. any other relevant information that is available.

Directions for Field Use

The SDG data collection pattern is shown in Figure 1, below. The SDG operates using a **cloverleaf pattern of five.** The first measurement is taken in the center and the remaining four, picking up the unit in between measurements, are moved 1 to 2 inches in a counter clockwise circle around the first measurement. The SDG will prompt the user to move the unit to the next location when it has completed a measurement. After the fifth measurement, the SDG will display the average coefficient values computed from the spectrum information of the five measurements just taken. The spectra information from each reading will be stored in the unit and can be uploaded to a computer. The unit can currently hold 500 individual measurements, or 100 "average of five" measurements.

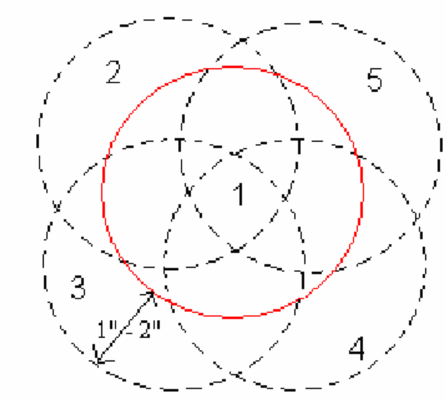


Figure 1. SDG Data Collection Pattern

For NDG testing in conjunction the SDG testing, the NDG needs to be operated in the **one minute measurement mode** with a **rod depth of four inches.** Industry experience has shown that the most accurate readings from the NDG are obtained with a rod depth of two to four inches. The NDG should be standardized as specified in its manual before use in the field and should have been in for its Factory Calibration within the last six months. The NDG data collection pattern of two or three measurements over the SDG data collection area is shown below in Figure 2. Ideally, we would prefer the three point measurements pattern for the NDG readings, but if there are time constraints, the two points will be sufficient. **Do not take SDG measurements over the NDG sensor hole!**

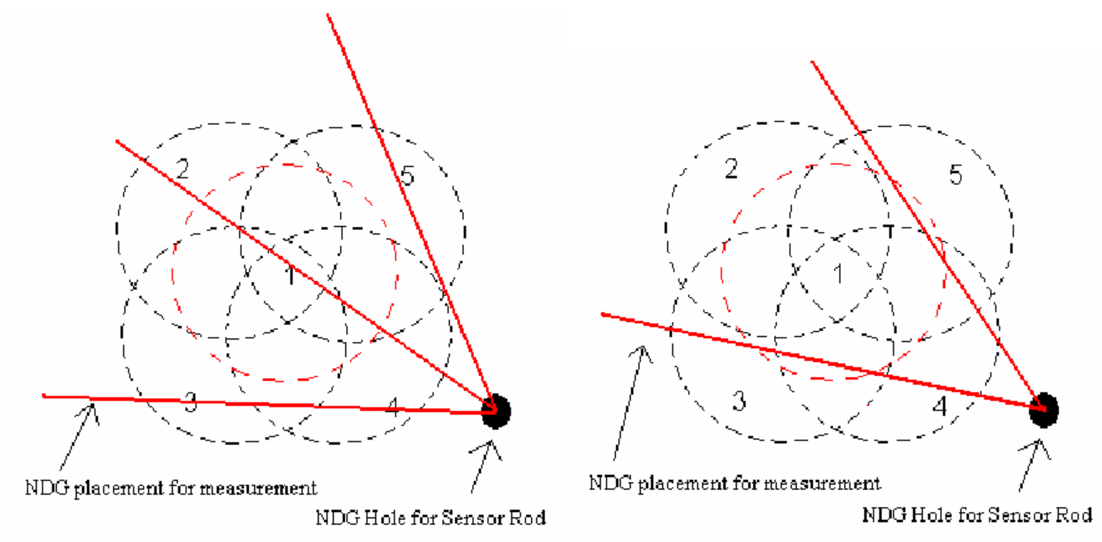


Figure 2. NDG Data Collection Pattern

When collecting data with the prototype Soil Density Gauge during the field test program, it is important to ‘see’ or monitor the slope of compaction; for that reason, when collecting data with the SDG, the **data needs to be collected during the compaction process.** Figure 3 shows a typical compaction density profile, from zero compaction passes to eight compaction passes, where one compaction pass is considered one roller pass or one vibratory compactor pass. While it is too tedious to measure the density after each compactor pass, we ask that you take three to four sets of data after three or four different compaction passes. For example, we ask that you take three to four data sets after one, two, four and eight compaction passes, for a total of 12 -16 data sets per complete compaction.

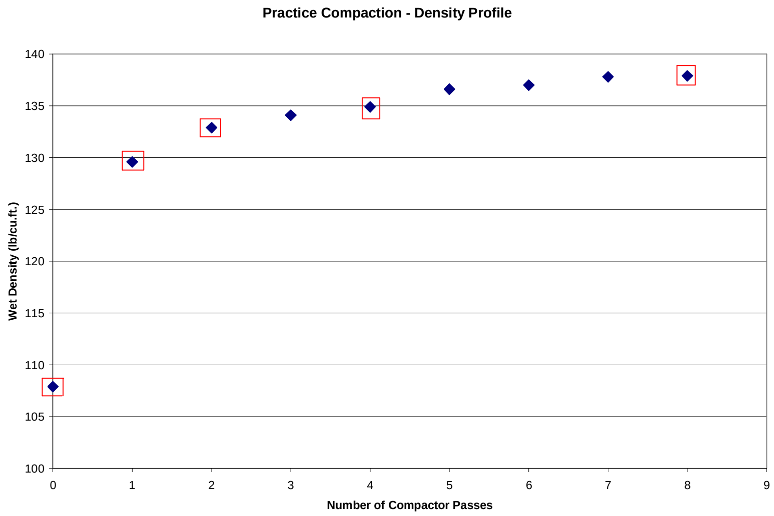


Figure 3. Typical Compaction Density Profile

While the prototype SDG unit stands off from the soil, surface condition is still important. The condition of the surface is also important to the accuracy of the NDG. It is necessary for the **soil surface to be free from any loose and disturbed material, stones, large air pockets or '*divots*' and other debris,** thus exposing the true surface of the material to be tested. It is also important that the **soil surface be flat.** If it is not flat, flatten the surface with a rigid plate or other suitable tool or move the unit to a location where the surface is more flat before taking the measurements. The **SDG should not rock side-to-side** when place in a location to take a measurement; if it does, move to a new location or remove the obstacle that is causing the rocking, being careful to not measure on top of any '*divot*' left by removal of the object. Again, **do not take SDG measurements over the NDG sensor hole!**

When choosing a location, the area should be appropriate for the SDG measurement and for the NDG measurements. No large metal objects, within three feet, should be around or underneath the soil while taking measurements. Measurements near buried power lines, within ten feet, should be avoided. Also, the NDG has a known edge *('vertical mass')* effect; therefore, if you are taking a measurement with the units near an edge, the NDG needs to be calibrated for that. If that NDG edge calibration cannot take place it should be noted with the measurements on the data collection sheet. The SDG does not have a large known edge *('vertical mass')* effect. If measurements are taken with an SDG near an edge, if possible, the SDG should to be three inches from the edge.

When placing the SDG at a location for a measurement, **do not push down on the unit** to 'seat' the unit in place. Set the unit down on the surface and check to see if it rocks side-to-side.

Do not touch unit while it is taking a measurement.

<u>Battery Charging</u>

After each day of testing, place the unit on the charger provided. Each unit will have a wall charger and a car charger in the case. When the unit's battery is charging, the charger light, located on the right side of the unit, will be red. The charger light will turn off when the unit's battery is completely charged. If it remains plugged in after the light turns off, the battery will not be damaged, i.e., it is safe to leave it plugged in overnight.

For your convenience, if needed, the unit can also be charged via the car charger, while on the job site. Please keep in mind that the **unit will not operate when it is charging.**

<u>Other Information</u>

For ***Sample Data Collection Sheets,*** see Appendix A. 1 and Appendix A.2. (Use which ever data collection/recording sheet your technician(s) feel comfortable with.)

For the ***SDG Software Layout,*** see Appendix B.

<u>Upload Data to Computer</u>

To upload SDG data to the computer, use VBTerm (i.e.,Visual Basic Terminal). VBTerm is free software available for all computers to download. TransTech Systems, Inc. has mailed or given a CD copy of the software for your use with the SDG. The software can easily be placed on any computer that is available to upload SDG data by *copying* and *pasting* the files TransTech Systems, Inc. sent to the computer's desktop. To keep all the files in one place, it is a good idea to create a folder, for example: *SDG_VBTerm_data,* and place the files inside. This only needs to be done once for each computer that the SDG is going to upload data too. Once on the desktop, open the folder and click on the yellow phone icon, this opens the VBTerm.

1. Open VBTerm (yellow phone icon)
    a. CommPort - Port Open
    b. CommPort - Properties
        i. Port: COM 1 (if this does not work, try COM 2)
        ii. Maximum Speed: 115200
        iii. Data Bits: 8
        iv. Parity: None
        v. Stop Bit: 1
        vi. Echo: Off
        vii. Flow Control: None
        viii. Click **OK**
    c. File - Open Log File
        i. Look in: select folder *SDG_VBTerm_data*
        ii. Type File name: OrganizationName_Date (year_month_date)
            1. Example file name: TransTechSys_070824
        iii. Select Files of type: (Log Files) *.LOG
        iv. Click **OPEN**
2. Connect SDG to Computer use RS232 cable

3. With SDG ON, press button *(3) Upload data to PC,* press button *(1) Upload data*

The data will now upload to the computer. When the unit has finished uploading the data, the data will stop streaming.

4. Disconnect the SDG from the computer.
5. Close the VBTerm Window. (A '*Run-time error'* may appear when you close out, just click OK)
6. If you did not save the file in the *SDG_VBTerm_data* folder, remember where you uploaded the data so it can be located and emailed to TransTech Systems, Inc.
7. Email the data file to Sarah Pluta at TransTech Systems, Inc. (email: spluta@transtechsys.com)

Contact Information

Field Operation/Logistical Contact:
Ron Berube
(Office) 518-370-5558 x 249
(Cell) 518-528-5291
(email) rberube@qcqalabs.com

Technical Contact:
Sarah Pluta
(Office) 518-370-5558 x 231
(email) spluta@transtechsys.com

Program Coordination:
John Hewitt
(Office) 518-370-5558 x 228
(email) jhewitt@transtechsys.com

Number of Compaction Passes:

	SDG (Avg 5)	**NDG**			2nd Moisture
		1	2	3	
Test Location 1					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Test Location 2					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Test Location 3					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Test Location 4					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Test Location 5					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					

Material Information

Proctor Information: Max Dry Density: ________ Optimum

Gradation Information: Liquid Limit (LL): ______ Plastic Index (PI):

Sieve	% passing
3.00” (75mm)	
2.00” (50mm)	
1.50” (3 8. 1mm)	
1.00” (25.40mm)	
0.75” (19mm)	
0.5” (12.67mm)	
0.375” (9.50mm)	
#4 (4.75mm)	
#8 (2.36mm)	
#10 (2.00mm)	
#16 (1.12mm)	
#20 (0.85mm)	
#30 (0.60mm)	
#50 (0.30mm)	
#100 (0.15mm)	
#200 (0.075mm)	

Test Location:

	SDG (Avg 5)	**NDG** 1	2	3	2nd Moisture
Number of Compaction Passes:					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Number of Compaction Passes:					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Number of Compaction Passes:					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Number of Compaction Passes:					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					
Number of Compaction Passes:					
Wet Density SDG (A)					
Dry Density SDG (B)					
% Moisture					

Material Information

Proctor Information:
Max Dry Density:
_______ Optimum

Gradation Information: Liquid Limit (LL): ______
Plastic Index (PI):

Sieve	% passing
3.00” (75mm)	
2.00” (50mm)	
1.50” (38.1mm)	
1.00” (25.40mm)	
0.75” (19mm)	
0.5” (12.67mm)	
0.375” (9.50mm)	
#4 (4.75mm)	
#8 (2.36mm)	
#10 (2.00mm)	
#16 (1.12mm)	
#20 (0.85mm)	
#30 (0.60mm)	
#50 (0.30mm)	
#100 (0.15mm)	
#200 (0.075mm)	

<u>SDG Software Layout</u>

(1) Measure

a. Choose Material (1-12)

i. Check gradation info / proctor info

ii. (Enter) = Select - Measure

1. Move unit to location 1 to 5 .....

a. Display data coefficients (*A* and *B)* iii. (Menu) = Exit

(2) Soil Setup

a. Maximum Dry Density = 000.0

b. Optimum Percent Moisture = 00.0

c. Lift Thickness = 00.0

d. Soil Characteristics/Gradation Information

i. Fine-Grained Soil (50% or more passes No. 200 Sieve)

1. Liquid Limit (LL) = 000.0
2. Plastic Index (PI) = 00.0

ii. Coarse-Grained Soil (50% Retained on No. 200 Sieve)

1. 3.00” (75mm) passing = 000.0
2. 2.00”(50mm) passing = 000.0
3. 1.50” (38.1mm) passing = 000.0
4. 1.00” (25.4mm) passing = 000.0
5. 0.75” (19mm) passing = 000.0
6. 0.50” (12.67mm) passing = 000.0
7. 0.375” (9.5mm) passing = 000.0
8. #4 (4.75mm) passing = 000.0
9. #8 (2.36mm) passing = 000.0
10. #10 (2.00mm) passing = 000.0
11. #16 (1.12mm) passing = 000.0
12. #20 (0.85mm) passing = 000.0
13. #30 (0.60mm) passing = 000.0
14. #50 (0.30mm) passing = 000.0
15. #100 (0.15mm) passing = 000.0
16. #200 (0.075mm) passing = 000.0

(3) Upload data to PC

a. Upload data to PC

b. Initialize memory ***(This will delete all stored data)*** i. Proceed?

(4) Diagnose Unit *(not enabled)*

a. Test Run on Standard Block

(5) Factory Settings *(password protected)*

APPENDIX B

SDG Controlled Field Test Density Data Analysis and Summary

Appendix B. SDG Controlled Field Test Density Data Analysis and Summary

A series of controlled field tests were conducted in order to secure data on a number of soils across the US in order to develop the algorithms necessary to convert the measured electromagnetic spectra to soil density and moisture. The listing of all the testing that was performed along with the location and soil type is presented in Table B-1. The soil type designation conforms to ASTM D 2487 – Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

ASTM Designation	Common Designation	Soil Source	Test Location	Test Type
SW	Well graded sand with silt	Callanan, Halfmoon, NY	TransTech	Compaction Task 3 (completed)
SW (varied CC)	Well graded sand with silt	Callanan, Halfmoon, NY	TransTech	Gradation Task 7 (completed)
GP-GM	Poorly graded gravel with silt & sand	LaFarge North America, Buffalo, NY	TransTech	Compaction Task 8 (completed)
GP-GM, GW, GW-GM, & SW	Poorly graded gravel with silt & sand, Well-graded gravel with sand, Well-graded gravel with silt & sand & Well-graded sand with silt	LaFarge North America, Buffalo, NY	TransTech	Gradation Task 7 (completed)
ML	Brown sandy silt	LaFarge North America, Buffalo, NY	TransTech	Gradation Task 7 (completed)
GP-GM	Poorly graded gravel with silt & sand	Callanan, Pattersonville, NY	Callanan. Pattersonville, NY	Controlled Field Test Task 14 (November 2007)
SP	Sand with gravel	Callanan, Wynantskill, NY	Callanan, Wynantskill, NY	Controlled Field Test Task 14 (November 2007)
GP-GM	Gray 1¼” crushed CSBC	ICON Materials, Seattle, WA	ICON Materials, Seattle, WA	Controlled Field Test Task 20 (January 2008)
SP	-4” Gravel Borrow	ICON Materials, Seattle, WA	ICON Materials, Seattle, WA	Controlled Field Test Task 20 (January 2008)
GP-GM	Poorly graded gravel with sand and silt	Qore Properties, Atlanta, GA	Qore Properties, Atlanta, GA	Controlled Field Test Task 20 (February 2008)
SM	Georgia Red Clay	Qore Properties, Atlanta, GA	Qore Properties, Atlanta, GA	Controlled Field Test Task 20 (February 2008)
GP-GM	Crushed stone sub-base	Martin Marietta, Dallas, TX	Martin Marietta, Dallas, TX	Controlled Field Test Task 20 (March 2008)
CM	Sandy Clay	Clough Harbour, Dallas, TX	Clough Harbour, Dallas, TX	Controlled Field Test Task 20 (March 2008)

Table B-1. Summary of Soil Testing

The major part of the Department of Homeland Security (DHS) Phase II contract is to collect as much carefully taken data, side by side with the Soil Density Gauge (SDG) and the Nuclear Density Gauge (NDG), as possible. The goal is to complete testing in four or five different geographic locations throughout the US to test on a variety of soil types and mineralogies. In addition to having the SDG units in the hands of various agencies, utilities, contractors, etc., to collect data on their actual job sites as part of our beta/field testing program, a series of controlled test sites throughout the country is also being setup.

The controlled test sites will utilize the contractor's own equipment and personnel to build a test bed and compact it one pass at a time so that side by side data on the full range of compaction levels, from uncompacted to fully compacted can be secured. In addition to taking extensive data with the NDGs and the SDGs, a number of soil samples will be taken for oven dry testing for moisture determination. In this way, "real world" data is collected as if it was on an actual construction site with the same equipment and personnel, but with the advantage of taking extensive and controlled data … as opposed to actual job sites where the contractor is not willing to allow the time necessary to take the amount and quality of data that is required. The large amount of data taken throughout the country will be used to upgrade the SDG's algorithms, i.e., make them as robust as possible for product use.

The SDG data collection pattern is shown in Figure B-1, below. The SDG operates using a **clover-leaf pattern of five**. The first measurement is taken in the center and the remaining four, picking up the unit in between measurements, are moved 1 to 2 inches in a counter clockwise circle around the first measurement. The SDG will prompt the user to move the unit to the next location when it has completed a measurement. After the fifth measurement, the SDG will display the average coefficient values computed from the spectrum information of the five measurements just taken. The spectra information from each reading will be stored in the unit and can be uploaded to a computer. The unit can currently hold 500 individual measurements, or 100 "average of five" measurements.

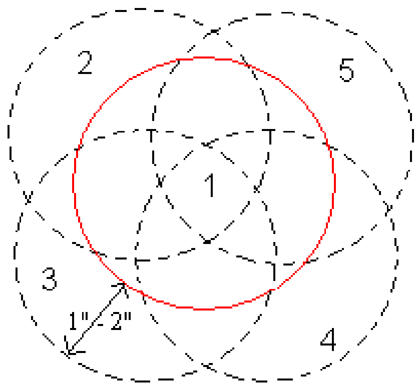


Figure B-1. SDG Data Collection Pattern

For NDG testing in conjunction the SDG testing, the NDG needs to be operated in the **one minute measurement mode** with a **rod depth of four inches**. Industry experience has shown that the most accurate readings from the NDG are obtained with a rod depth of two to four inches, mainly because the moisture measurement is taken from the surface in backscatter mode. The NDG should be standardized as specified in its manual before use in the field and should have been in for its Factory Calibration within the last six months. The NDG data collection pattern of two or three measurements over the SDG data collection area is shown below in Figure B-2. Ideally, we would prefer the three point measurements pattern for the NDG readings, but if there are time constraints, the two points will be sufficient. *When taking the NDG measurements, the NDG should not be slid across the soil's surface to the next measurement location; it should be lifted up and set back down on the next measurement location*.

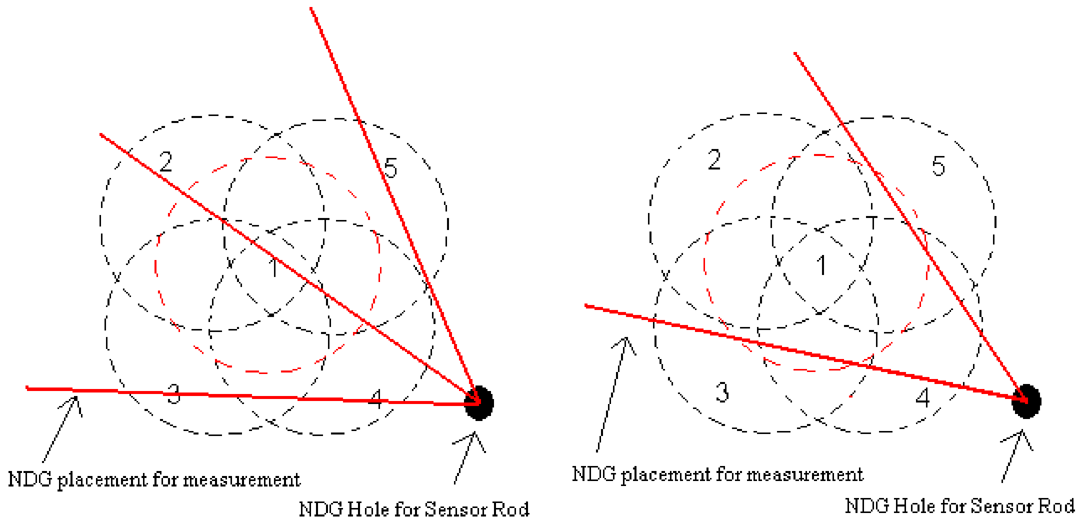


Figure B-2. NDG Data Collection Pattern

While the prototype SDG unit stands off from the soil, surface condition is still important. The condition of the surface is also important to the accuracy of the NDG. It is necessary for the **soil surface to be free from any loose and disturbed material, stones, large air pockets or '*divots*' and other debris**, thus exposing the true surface of the material to be tested. It is also important that the **soil surface be flat**. If it is not flat, flatten the surface with a rigid plate or other suitable tool or move the unit to a location where the surface is more flat before taking the measurements. The **SDG should not rock side-to-side** when placed in a location to take a measurement; if it does, move to a new location or remove the obstacle that is causing the rocking, being careful to not measure on top of any '*divot*' left by removal of the object.

When choosing a location, the area should be appropriate for the SDG measurement and for the NDG measurements. No large metal objects, within three feet, should be around or underneath the soil while taking measurements. Measurements near buried power lines, within ten feet, should be avoided. If unavoidable, it should be documented in the margin of the notes as to the distance to the object or power line. Also, the NDG has a known edge ('*vertical mass*') effect; therefore, if there is a measurement with the units near an edge, the NDG needs to be calibrated for that. If that NDG edge calibration cannot take place, it should be noted with the measurements on the data collection sheet. The SDG does not have a large known edge ('*vertical mass*') effect. If measurements are taken with an SDG near an edge, if possible, the SDG should to be three inches from the edge.

*When placing the SDG at a location for a measurement, **<u>do not push down on the unit</u>** to 'seat' the unit in place, especially at the lower compaction levels. Set the unit down on the surface and check to see if it rocks side-to-side*. When moving the unit around to each of the five locations in the clover-leaf pattern, pick it up and set it down each time, again, not pushing down on the unit. If it is dragged or pushed around while in contact with the surface, ridges may develop that may results in loose soil touching the sensor plate.

The protocol for the controlled field tests is designed to collect as much data on each compaction level with the SDG and NDG as possible. The test pad will be approximately 10 ft. x 40 ft. This will allow for the test pad to be broken up into four sections, each with an approximate size of 10 ft. x 10 ft. With a test pad area of 400 sq. ft. and a minimum lift thickness of 12 inches, the approximate volume is 14.8 cubic yards.

After the material is placed (12" minimum lift), the data collection process will usually begin after one roller pass has been completed. One roller pass is defined as a single pass in one direction. *The uncompacted level should only be measured with the SDG and NDG if the material being compacted can be walked on without sinking into the material to a substantial degree.* Then, following each additional roller pass, sets of SDG and NDG data will be taken, until the soil is fully compacted. For example, data will be collected at 1 roller pass, 2 roller passes, 3 roller passes and 4 roller passes. If the material is expected to take more than 3 or 4 roller passes, the data collection pattern should be something similar to this – 1 roller pass, 2 roller passes, 4 roller passes and 6 roller passes.

The data collection pattern to be followed by the SDG and NDG is shown in Figure B-3. Depending on the size of the test pad and any time constraints, the amount of data taken with the SDGs and NDG may vary. However, no less than two NDG measurements should be taken for each pattern of five SDG measurement. For example, if there is enough space for all four testing areas (i.e., A, B, C and D) and three test points in each area (i.e., 1, 2 and 3), then two NDG measurements at each of the 12 locations, instead of three, is more realistic. With two NDG measurements at each location, it will take a minimum of 48 minutes to complete the NDG data collection on each compaction level.

If more than one NDG is being used at the test site, they should be kept at a minimum of 20 ft. apart during measurements (ASTM recommendation is 30 ft.). For example NDG(1) can start its measurement and data collection process in area *A1*, while NDG(2) can start measurement and data collection in area *C1*. In this way, NDG(1) can take measurements on *A1-A3* and then *B1-B3*, while NDG(2) is taking measurements on areas *C1-C3* and then *D1-D3*. After completing the two rows, the NDG units can switch positions and NDG(2) will measure areas *A1-A3* and *B1-B3*, while NDG(1) measures *C1-C3* and *D1-D3*.

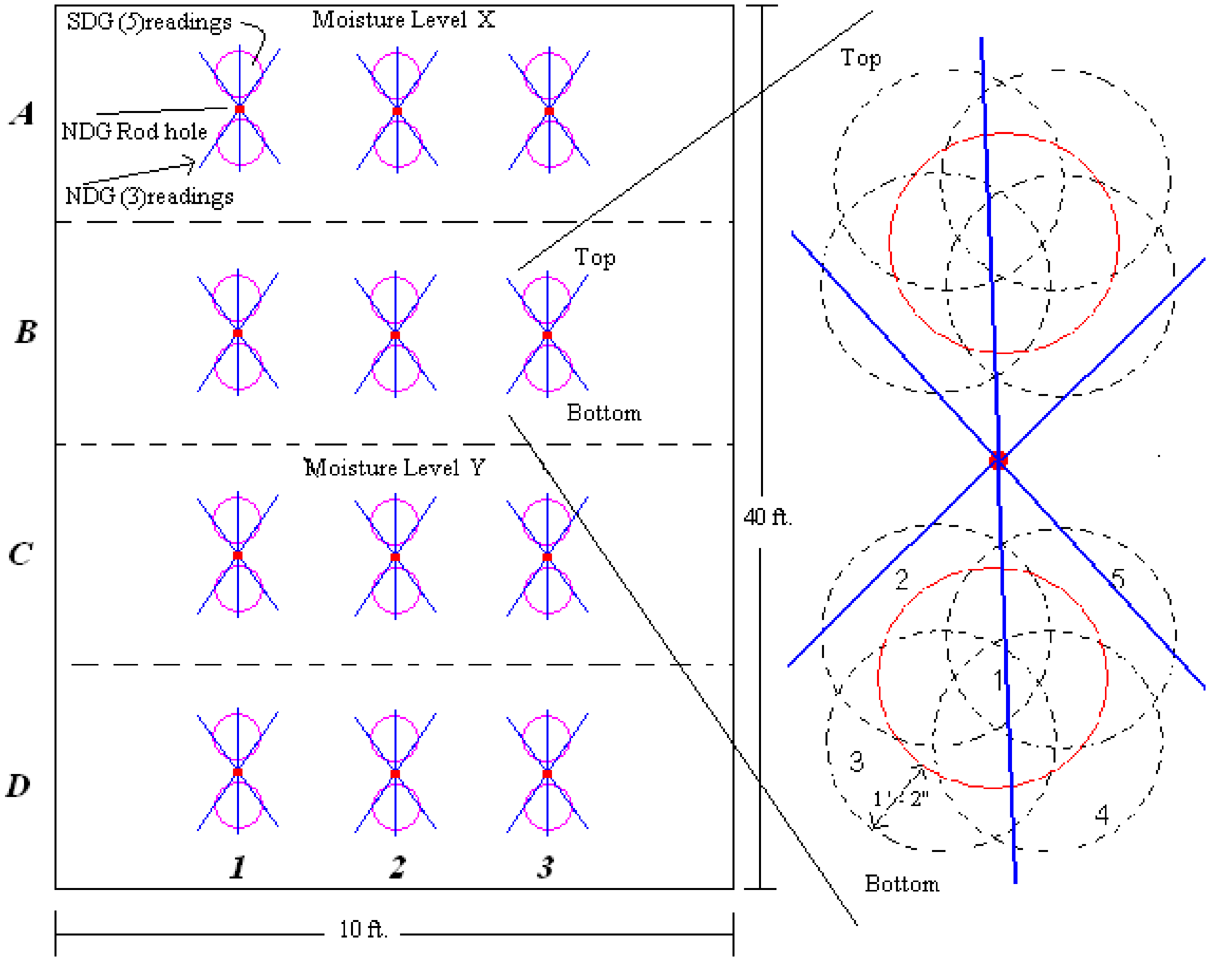


Figure B-3. SDG/NDG Data Collection Pattern (* Figure not drawn to scale *)

Material for oven dries needs to be taken from the same areas as the SDG/NDG measurement areas, before the testing begins and after the compaction tests are finished. The material from each location (200 to 500 grams) should be placed in a clearly labeled container (i.e., zip lock baggie), for transport back to TransTech Systems, Inc or a designated testing facility.

If the material for the controlled test is dry enough to allow it, completing the same tests at a second moisture level, for example in test areas C and D, will be done.

Material from each field calibration site needs to be sent back to TransTech Systems, Inc. or a designated testing facility for a gradation analysis and Proctor Test (i.e., approx. 50 to 60 lbs). If the same material that will be used during the field calibration compaction test is available before the compactions take place, a sample should be sent to TransTech Systems, Inc. for a pre-controlled compaction gradation analysis and Proctor Test (i.e., if material is available beforehand, gradation analysis and Proctor Test will be performed before as well as after the controlled compaction).

Figure D-4. Field Testing in Georgia

Figure D-5. Field Testing In Washington

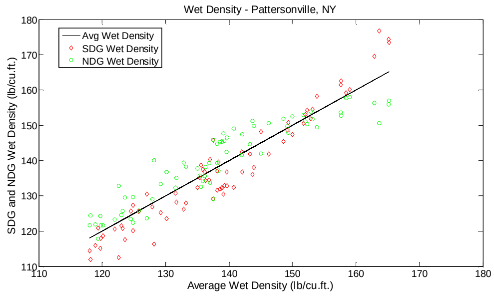
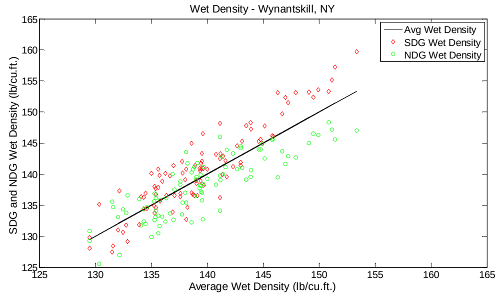
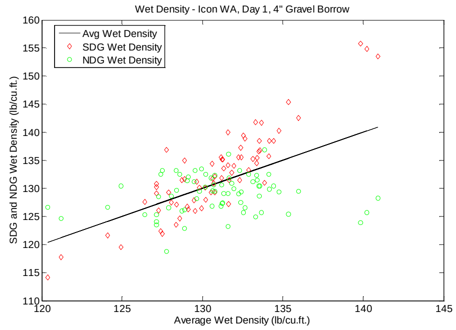
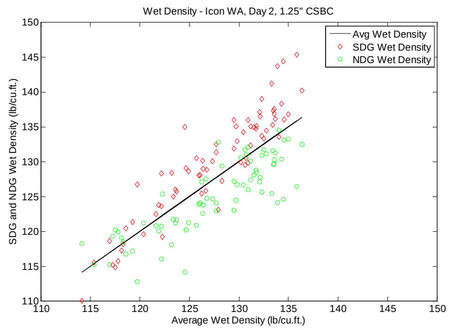
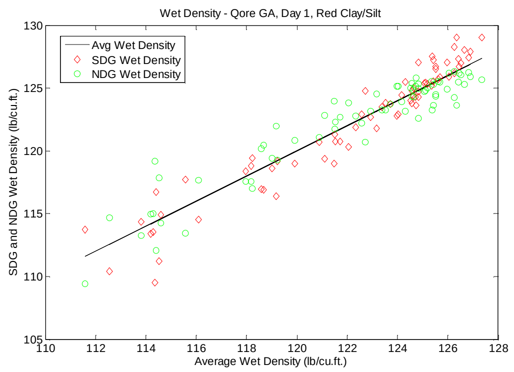
Figures B-4 and B-5 show the field testing in Georgia and Washington.

The ASTM/USCS designation nomenclature and the common name for the soils tested are presented in Table B-2.

	USCS	Common Name
1	***GP-GM***	Crushed Stone
2	***SP***	Run of Bank Sand
3	***SP***	4” Gravel Borrow
4	***GP-GM***	1 ¼” Crushed Base Course
5	***CL***	Red Silt Clay
6	***GP-GM***	Graded Aggregate Base
7	***GW-GM***	Red Sand with Rock
8	***CL-ML***	Red Sandy Clay

Table B-2. ASTM/USCS Soil Designations

Table B-3 presents the the wet density results of the four National Field Tests; at each site two different commonly used local materials were tested. In the following eight plots, the x-axis is the average wet density of the NDG and the SDG and the y-axis is the SDG and NDG wet density results. This method of evaluation was used since the actual wet density of the material under test was not known, therefore we are comparing two measurement methods, i.e., impedance spectroscopy and nuclear, with no known truth. The location, material, common name of the material, Proctor information and average difference between the average wet density and the SDG wet density for each of the eight materials is listed on the left side of the corresponding wet density figure.

Location: Albany, NY (Pattersonville) Material: GP-GM (ROC) Common Name: Crushed Stone Sub-base Proctor: 149.3 lb/ft^3 at 4.4% Average Difference: 1.5 lb/ft^3	
Location: Albany, NY (Wynantskill) Material: SP (ROB) Common Name: Sand with gravel Proctor: 137.6 lb/ft^3 at 7.4% Average Difference: 1.3 lb/ft^3	
Location: Seattle, WA (ICON) Material: SP (ROB) Common Name: -4” Gravel borrow Proctor: 132.0 lb/ft^3 at 9.5% Average Difference: 1.9 lb/ft^3	
Location: Seattle, WA (ICON) Material: GP-GM (ROC) Common Name: Gray -1 ¼” CSBC (crushed stone base course) Proctor: 138.0 lb/ft^3 at 9.5% Average Difference: 2.5 lb/ft^3	
Location: Duluth, GA(Qore) Material: CL Common Name: Ga Red Clay Proctor: 102.8 lb/ft^3 at 19.7% Average Difference: 0.0 lb/ft^3 (Specific Calibration – 1st Clay)	

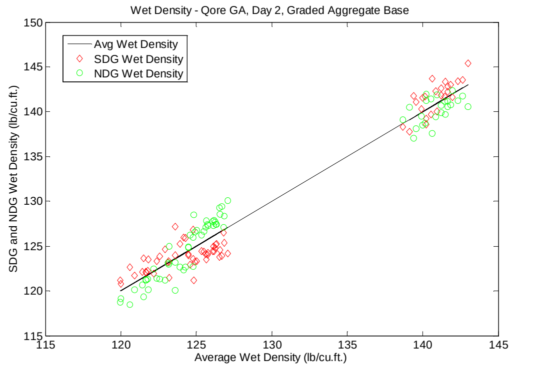
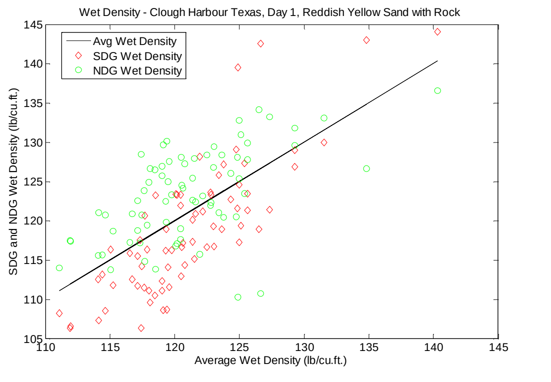
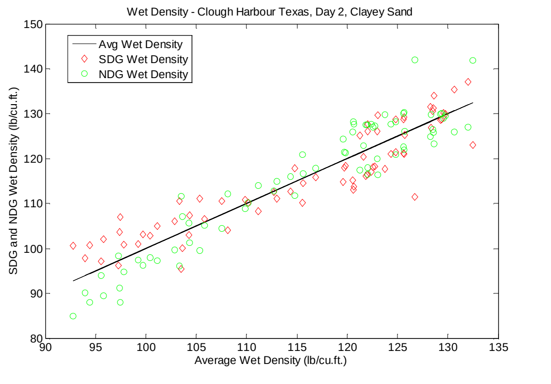
Location: Duluth, GA (Qore) Material: GP-GM Common Name: Graded Aggregate Base Proctor: 136.9 lb/ft^3 at 6.5% Average Difference: 0.0 lb/ft^3 (Specific Calibration – 1st Open Graded Material)	
Location: Texas (Clough Harbour) Material: GW-GM Common Name: Reddish Yellow Sand with Rock Proctor: 132.5 lb/ft^3 at 9.0% Average Difference: 2.3 lb/ft^3	
Location: Texas (Clough Harbour) Material: CL-ML Common Name: Clayey Sand Proctor: 118.3 lb/ft^3 at 12.5% Average Difference: 0.1 lb/ft^3	

Table B-3. Wet Density Results for the Four National Tests

The resulting data can be summarizes by examining the average difference in the readings at each point between the SDG and the NDG. This is shown in Table B-4. Given the state of the development of the SDG, the results are very encouraging. Additional improvements in the conversion algorithms will be made as further data is obtained during Beta testing and other testing.

Soil Classification	GP-GM	SP	SP	GP-GM	CL	GP-GM	GW-GM	CL-ML
Avg. Volumetric Moisture Difference between an SDG and an NDG (%)	2.6*	0.3	*2.1***	*4.1***	0.0	0.0	0.4	1.1
Avg. Wet	3.0*	2.6	*3.8***	*5.0***	0.0	0.0	2.6	0.2

Density Difference between an SDG and an NDG (%) (lb/cu.ft.)								

Table B-4. Average Volumetric Moisture Differences and Wet Density Differences from Controlled National Field Tests

*(Note *: Due to rain, limited moisture samples were taken.)*

*(Note **: Temperature correction may be necessary for soil that is at or near freezing.)*

APPENDIX C

SDG Controlled Field Test Moisture Data Analysis and Summary

Appendix C. SDG Controlled Field Test Moisture Data Analysis and Summary

Moisture Summary (Large Box, Small Box & Controlled National Field Tests)

The SDG measures volumetric moisture and calculates gravimetric moisture using the measured volumetric moisture and wet density. The basic volumetric moisture algorithm was developed using the data collected during the five 'Large Box' compactions and modified with the six 'Small Box' compactions due to gradation. As with the wet density, a material's gradation also has an effect on the unit's moisture measurement. Therefore, the six 'Small Box' gradation tests were designed to determine which aspect of a materials gradation was the controlling aspect of the SDG's frequency measurement response. Finally, the 'Controlled National Field Tests' were used to verify the moisture algorithm. During the field tests, it was found that the temperature of the soil is likely to have an impact on the measurement of moisture. While at the Icon facility in Washington State, the testing was completed on soil at freezing temperatures. This might be the reason for the higher moisture measurements on these two test days. The dielectric constant of ice is higher that the dielectric constant of liquid water. Further investigation of the field data will be necessary to verify this.

Large Box Moisture Results

For the 'Large Box' test, one material, with a USCS Soil Classification of GP-GM (Poorly graded gravel with silt and sand), was compacted at five different moisture levels. The results of the SDG's volumetric moisture results are shown in Figure 1. The average SDG volumetric moisture difference from the control was -0.6%. The volumetric moisture control was calculated using the oven dry results (i.e., gravimetric moisture) and the NDG's wet density measurement. The results of the SDG's gravimetric moisture results for the 'Large Box' compactions are shown in Figure 2. The average SDG gravimetric moisture difference from the control (i.e., oven dry results) was -0.3%.

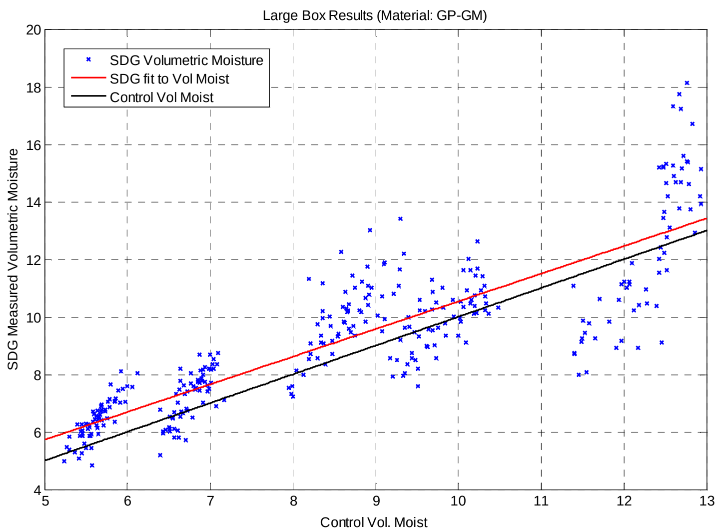


Figure 1. Large Box Volumetric Moisture Results

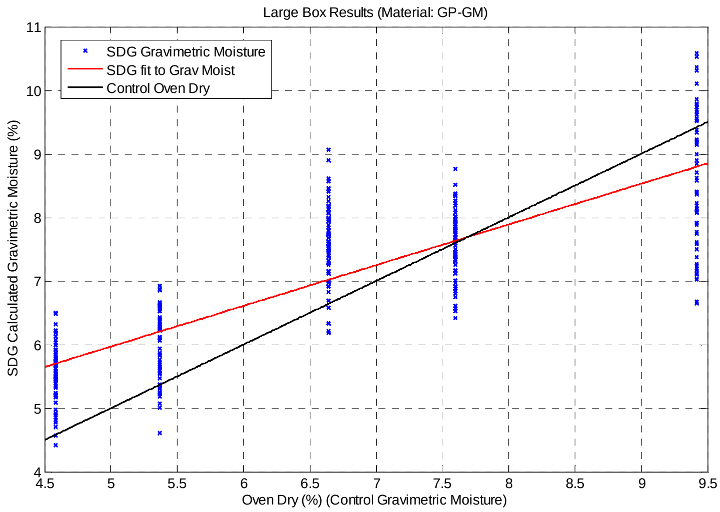


Figure 2. Large Box Gravimetric Moisture Results

Small Box Moisture Results

For the 'Small Box' test, five different soil classifications were tested. One soil classification was tested at two different moisture levels; therefore, six small box compactions were completed. The USCS soil classifications of the tested materials were:

1) GP-GM (Poorly graded gravel with silt and sand)
2) GW (Well-graded gravel with sand)
3) SW (Well-graded sand)
4) GW-GM at 2 Moistures (Well-graded gravel with silt and sand)
5) ML (Silt)

The results of the SDG's volumetric moisture results from the small box compactions are shown in Figure 3. Table 1, below, shows the average SDG volumetric moisture difference from the control volumetric calculation for each of the six tests. The average SDG volumetric moisture difference from the control was 1.3%. As in the 'Large Box' compactions, the control volumetric moisture values were calculated using the oven dry results and the NDG's wet density measurements. The results of the SDG's gravimetric moisture results for the 'Small Box' compactions are shown in Figure 4. Below in Table 2, the average SDG gravimetric moisture difference from the control (i.e., oven dry results) was 0.6%.

Volumetric Moisture:

Soil Classification	GP-GM	GW	SW	GW-GM Moist 1	GW-GM Moist 2	ML	Avg
Avg. SDG Volumetric Moisture Difference (%)	-1.4	0.3	0.6	-3.7	0.5	0.3	1.3

Table 1. Small Box Volumetric Moisture Results

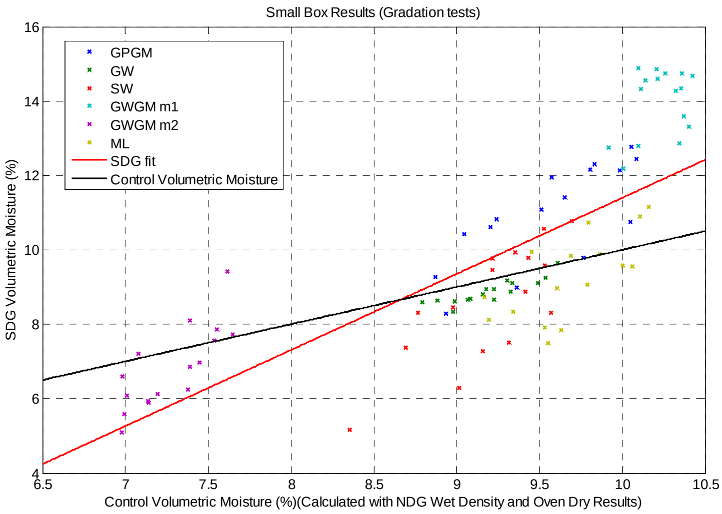


Figure 3. Small Box Volumetric Moisture Results

Gravimetric Moisture:

Soil Classification	GP-GM	GW	SW	GW-GM Moist 1	GW-GM Moist 2	ML	Avg
Avg. SDG Gravimetric Moisture Difference (%)	-0.9	0.1	0.5	-1.7	-0.1	0.5	0.6

Table 2. Small Box Gravimetric Moisture Results

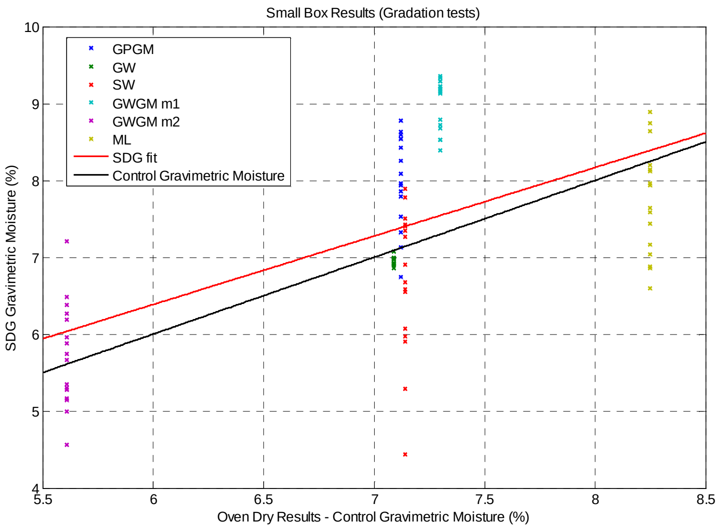


Figure 4. Small Box Gravimetric Moisture Results

Controlled National Field Tests

The 'Controlled National Field Tests' were conducted at four locations throughout the United States; two compactions were completed at each location with different materials. Included in Table 3 is the USCS soil classification and common name for each of the eight materials tested. In seven of the eight field tests, 12 moisture samples were pulled from the marked test sites before testing began and after testing was completed, 24 moisture samples were pulled, one from each of the 24 test sites. At the first test, completed in Pattersonville, NY, due to the rain, only four moisture samples were collected from the side area of the test pad. Table 4 displays the average SDG volumetric moisture difference from the control volumetric moisture for each of the eight tests. The average SDG volumetric moisture difference from the control volumetric moisture calculation for all eight soil tests was 1.3%. Two of the tests, both noted with an *****, were conducted at or near freezing temperatures. This may be one reason why the differences are high for these tests and will require further investigation incase a temperature correction is needed. As the temperature of water decreases, its dielectric constant increases. Table 5 shows the eight materials tested with the SDG volumetric moisture versus the control volumetric moisture. On the left of each figure is the location of the test, material tested, proctor information and average difference from the control volumetric moistures.

Table 6 displays the average SDG's gravimetric moisture difference from the oven dry moistures for each of the eight tests. The average SDG gravimetric moisture difference from the control gravimetric moisture measurement (i.e., oven dry moistures) for all eight soil tests was 1.1%. Also included in the table is the average NDG gravimetric moisture difference from the oven dry moistures for each of the eight materials tested. The average NDG gravimetric moisture difference for all eight soil tests was 1.5%. As before, two of the tests, both noted with an *****, were conducted at or near freezing temperatures. This may be one reason why the differences are high for these tests and will require further investigation. Since the NDG does not measure soil properties in the same way as the SDG does, it is less affected by soil temperature at or near freezing. Table 7 shows the eight materials tested with the SDG gravimetric moisture versus the control gravimetric moisture. In the table, the SDG results are shown with the red diamonds and the NDG gravimetric moisture results are shown with the green circles. On the left of each figure is the location of the test, material tested, proctor information and the SDG's average difference from the oven dry moistures.

USCS Soil Classifications:

	USCS	**Common Name**
1	***GP-GM*** (Poorly graded gravel with silt & sand)	Crushed Stone
2	***SP*** (Poorly graded sand with gravel)	Run of Bank Sand
3	***SP*** (Poorly graded sand with gravel)	4" Gravel Borrow
4	***GP-GM*** (Poorly graded gravel with silt & sand)	1 ¼" Crushed Base Course
5	***CL*** (Lean clay)	Red Silt Clay
6	***GP-GM*** (Poorly graded gravel with silt & sand)	Graded Aggregate Base
7	***GW-GM*** (Well graded gravel with silt & sand)	Red Sand with Rock
8	***CL-ML*** (Silty clay)	Red Sandy Clay

Table 3. Soil Classifications

Volumetric Moisture:

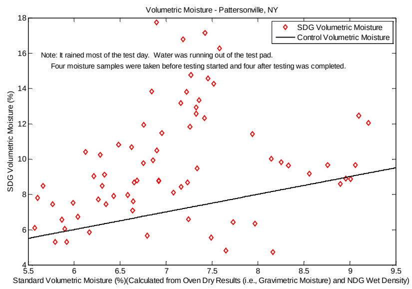
Soil Classification	GP-GM	SP	SP	GP-GM	CL	GP-GM	GW-GM	CL-ML
Avg. SDG Volumetric Moisture Difference (%)	2.6*	0.3	*2.1***	*4.1***	0.0	0.0	0.4	1.1

Table 4. Average Volumetric Moisture Differences from Controlled National Field Tests

*(Note *: Due to rain, limited moisture samples were taken.)*

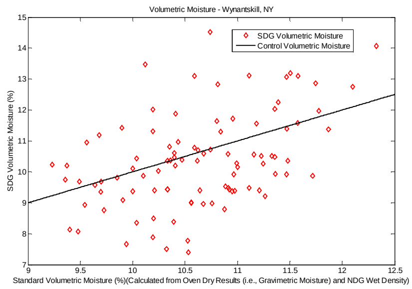
*(Note **: Temperature correction may be necessary for soil that is at or near freezing.)*

Location: Albany, NY (Pattersonville)
Material: GP-GM (ROC)
Common Name: Crushed Stone Sub-base
Proctor: 149.3 lb/ft^3 at 4.4%
Average Difference: 2.6%

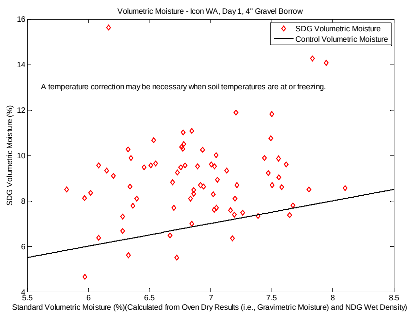


*** Note**: It rained most of the test day. Water was running out of the test pad. Four moisture samples were taken before testing started and four after testing was competed.

Location: Albany, NY (Wynantskill)
Material: SP (ROB)
Common Name: Sand with gravel
Proctor: 137.6 lb/ft^3 at 7.4%
Average Difference: 0.3%

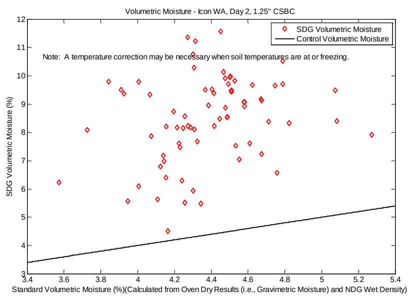


Location: Seattle, WA (ICON)
Material: GP-GM (ROB)
Common Name: -4" Gravel borrow
Proctor: 132.0 lb/ft^3 at 9.5%
Average Difference: 2.1%



*** Note**: A temperature correction may be necessary when soil temperatures are at or near freezing.

Location: Seattle, WA (ICON)
Material: GW (ROC)
Common Name: Gray -1 ¼" CSBC (crushed stone base course)
Proctor: 138.0 lb/ft^3 at 9.5%
Average Difference: 4.1%



*** Note**: A temperature correction may be necessary when soil temperatures are at or near freezing.

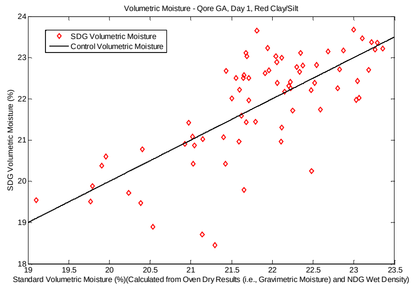
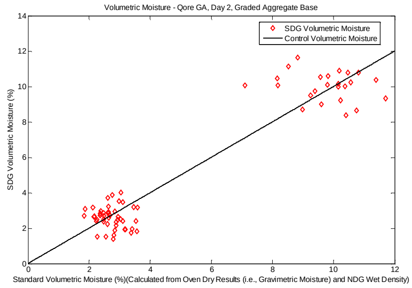
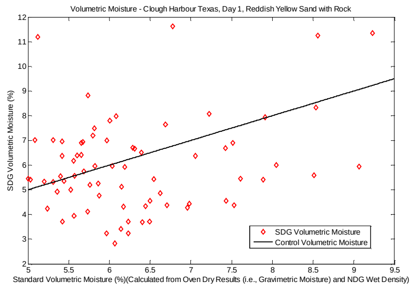
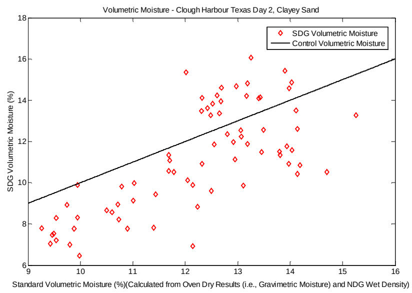
Location: Duluth, GA(Qore) Material: CL Common Name: Ga Red Clay Proctor: 102.8 lb/ft^3 at 19.7% Average Difference: 0.0% (Specific Calibration – 1st Clay)	
Location: Duluth, GA (Qore) Material: GP-GM Common Name: Graded Aggregate Base Proctor: 136.9 lb/ft^3 at 6.5% Average Difference: 0.0% (Specific Calibration – 1st Open Graded Material)	
Location: Texas (Clough Harbour) Material: GW-GM Common Name: Reddish Yellow Sand with Rock Proctor: 132.5 lb/ft^3 at 9.0% Average Difference: 0.4%	
Location: Texas (Clough Harbour) Material: CL-ML Common Name: Clayey Sand Proctor: 118.3 lb/ft^3 at 12.5% Average Difference: 1.1%	

Table 5. Figures of Volumetric Moisture Results from Controlled National Field Test

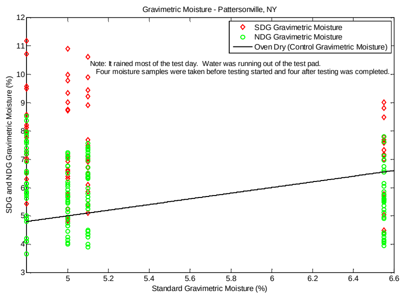
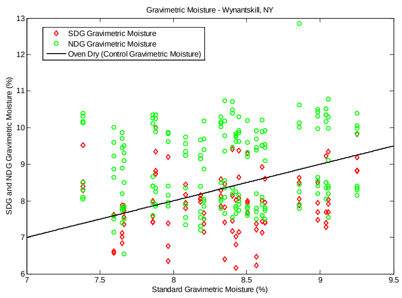
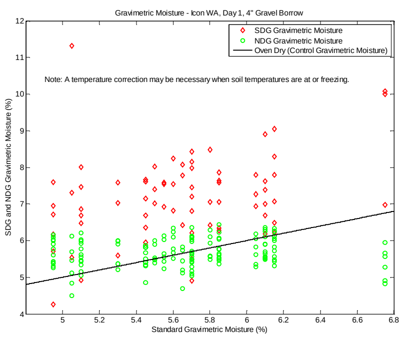
Gravimetric Moisture:

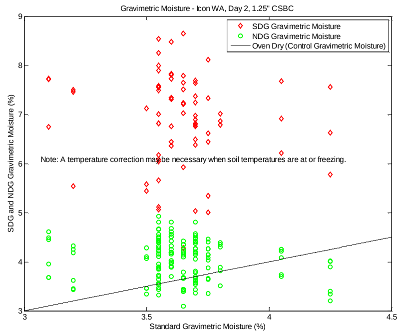
Soil Classification	GP-GM	SP	SP	GP-GM	CL	GP-GM	GW-GM	CL-ML
Avg. SDG Gravimetric Moisture Difference (%)	2.1*	0.4	1.5**	3.3**	0.0	0.0	0.2	1.3
Avg. NDG Gravimetric Moisture Difference (%)	0.8	0.9	0.3	0.4	6.4	0.8	1.5	1.2

Table 6. Average Gravimetric Moisture Differences from Controlled National Field Tests

*(Note *: Due to rain, limited moisture samples were taken.)*

*(Note**: Temperature correction may be necessary for soil that is at or near freezing.)*

<table>
<tr>
<td>Location: Albany, NY (Pattersonville)
Material: GP-GM (ROC)
Common Name: Crushed Stone Sub-base
Proctor: 149.3 lb/ft^3 at 4.4%
Average Difference: 2.1%</td>
<td>
</td>
<td>* Note: It rained most of the test day. Water was running out of the test pad. Four moisture samples were taken before testing started and four after testing was competed.</td>
</tr>
<tr>
<td>Location: Albany, NY (Wynantskill)
Material: SP (ROB)
Common Name: Sand with gravel
Proctor: 137.6 lb/ft^3 at 7.4%
Average Difference: 0.4%</td>
<td>
</td>
<td></td>
</tr>
<tr>
<td>Location: Seattle, WA (ICON)
Material: GP-GM (ROB)
Common Name: -4” Gravel borrow
Proctor: 132.0 lb/ft^3 at 9.5%
Average Difference: 1.5%</td>
<td>*
or

</td>
<td>Note: A temperature correction may be necessary when soil temperatures are at near freezing.</td>
</tr>
</table>

<table>
<tr>
<td>Location: Seattle, WA (ICON)
Material: GW (ROC)
Common Name: Gray -1 ¼” CSBC (crushed stone base course)
Proctor: 138.0 lb/ft^3 at 9.5%
Average Difference: 3.3%</td>
<td>

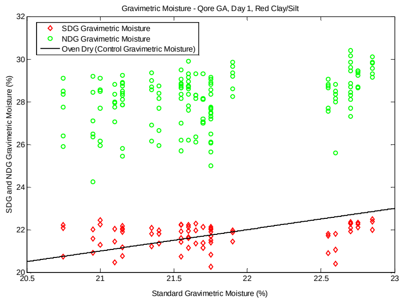
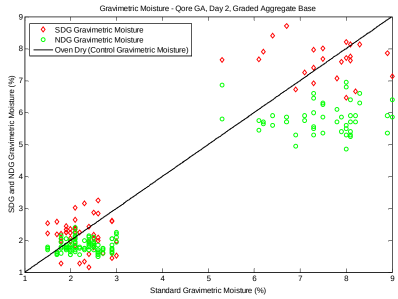
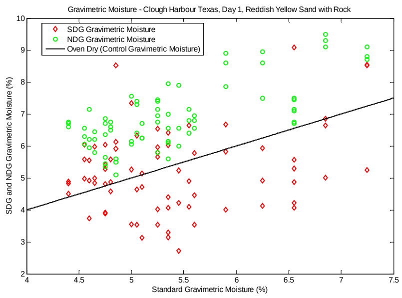
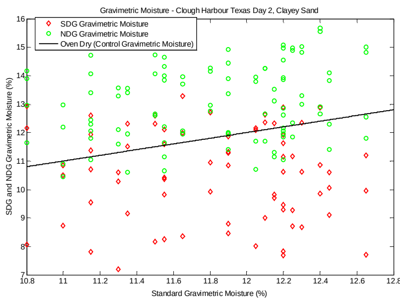
* **Note**: A temperature correction may be necessary when soil temperatures are at or near freezing.</td>
</tr>
<tr>
<td>Location: Duluth, GA(Qore)
Material: CL
Common Name: Ga Red Clay
Proctor: 102.8 lb/ft^3 at 19.7%
Average Difference: 0.0%
(Specific Calibration – 1st Clay)</td>
<td>
</td>
</tr>
<tr>
<td>Location: Duluth, GA (Qore)
Material: GP-GM
Common Name: Graded Aggregate Base
Proctor: 136.9 lb/ft^3 at 6.5%
Average Difference: 0.0%
(Specific Calibration – 1st Open Graded Material)</td>
<td>
</td>
</tr>
<tr>
<td>Location: Texas (Clough Harbour)
Material: GW-GM
Common Name: Reddish Yellow Sand with Rock
Proctor: 132.5 lb/ft^3 at 9.0%
Average Difference: 0.2%</td>
<td>
</td>
</tr>
<tr>
<td>Location: Texas (Clough Harbour)
Material: CL-ML
Common Name: Clayey Sand
Proctor: 118.3 lb/ft^3 at 12.5%
Average Difference: 1.3%</td>
<td>
</td>
</tr>
</table>

Table 7. Figures of Gravimetric Moisture Results from Controlled National Field Test

APPENDIX D

NDG Controlled Field Testing Procedures and Results

Appendix D. NDG Controlled Field Testing Procedures and Results

Test Program Procedures

During a field test program to evaluate soil density gauges, TransTech secured data with a variety of Nuclear Density Gauges (NDG) on eight different soil types at various levels of compaction. The test program was conducted at locations in New York, Georgia, Oklahoma, Texas, and Washington. The tests were conducted by placing a 12-inch layer of the various types of soil over 10-foot by 40-foot area. This area was typically divided into 12 test areas as shown in Figure 1. The NDG rod hole was located in approximately the center of each test area. The test pattern for the NDG is each area is shown in Figure 2. Four readings were taken about a fixed rod hole location.

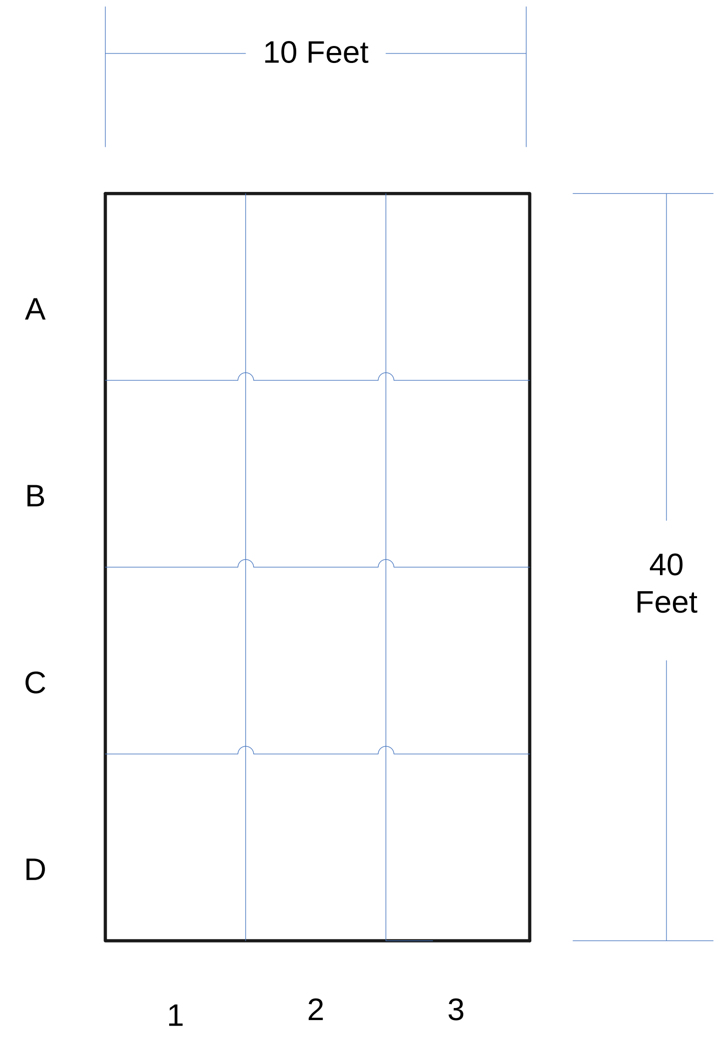


Figure 1. Test Area Designations on the Test Soil

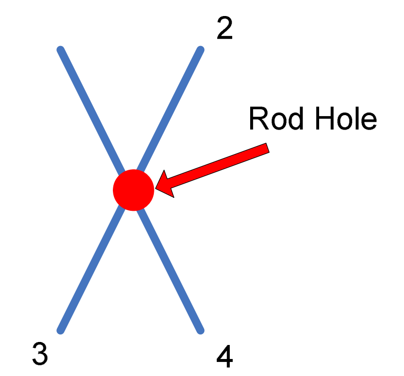


Figure 2. NDG Test Pattern

A total of nine NDG units from three manufactures were used in the testing. The NDG units were owned by five different organizations and operated by personnel from the owner organization. The NDGs used in this study included: 1) CPN MC-3; 2) Troxler 75-5594 (Serial Number 23531); 3) MD10506170; 4) Troxler 3450 (Serial Number 1013); 5) Troxler (Serial Number 38379); 6) Troxler (Serial Number 39576); 7) Humboldt 5001-EZ (Serial Number 2523); 8) Humboldt 5001 (Serial Number 102); and 9) Troxler (Serial Number 6964).

The test procedure was to have the soil rough graded and then compacted with a vibrating roller. The equipment was provided by the quarry operator. Data were taken at three or four compaction levels depending on the soil type. Data were taken after one pass of the roller and then after a number of passes until the soil was fully compacted. The number of passes is noted in the data tables below.

The data for each soil is presented and then a summary of the data from all the NDG units on all the soils is presented.

Soil 1. Run-of-bank (ROB) Gravel (USCS: SP), Wynantskill, NY

The material in Tables 1 and 2 is a **Run-of-Bank (ROB) Gravel**, with a USCS classification of SP (i.e., poorly graded sand). The material was from a quarry in Wynantskill, NY and the testing was conducted at the quarry by TransTech Personnel with TransTech units.

For this material only, the wet density data from all 48 readings are presented for a single compaction level, full compaction (14 roller passes). For the remainder, only an average of the 48 readings for each compaction level is presented. The variations observed in Table 1 are similar to those observed on all the readings.

Location	MC-3	Troxler 23531	Absolute Difference
1A-1	138.2	140.8	2.6
1A-2	136.5	139.8	3.3
1A-3	141.4	141.2	0.2
1A-4	142	142.4	0.4
1A average	139.53	141.05	1.5
1A std dev	2.62	1.08	
1B-1	138.4	142.5	4.1
1B-2	138	139.4	1.4
1B-3	141.5	145.2	3.7
1B-4	139	144.4	5.4
1B average	139.23	142.88	3.7
1B std dev	1.57	2.58	
1C-1	139	142.8	3.8
1C-2	139.6	142.5	2.9
1C-3	141.6	144.2	2.6
1C-4	137.2	141.5	4.3
1C average	139.35	142.75	3.4
1C std dev	1.81	1.12	
1D-1	142.3	145.9	3.6
1D-2	138.2	140.2	2.0
1D-3	144.1	145.9	1.8
1D-4	142.8	143	0.2
1D average	141.85	143.75	1.9
1D std dev	2.55	2.73	

2A-1	145.7	145.1	0.6
2A-2	144.7	144.2	0.5
2A-3	142.2	144	1.8
2A-4	143.7	146.6	2.9
2A average	144.08	144.98	0.9
2A std dev	1.49	1.18	
2B-1	142.2	147	4.8
2B-2	143.7	146.7	3.0
2B-3	146.3	146.9	0.6
2B-4	142.3	147.3	5.0
2B average	143.63	147.98	4.3
2B std dev	1.91	0.25	
2C-1	143.6	147.4	3.8
2C-2	146.2	150.8	4.6
2C-3	145.5	149.4	3.9
2C-4	145.1	148.7	3.6
2C average	145.1	149.08	4.0
2C std dev	1.1	1.42	
2D-1	144.8	148.9	4.1
2D-2	144.4	148.1	3.7
2D-3	145.2	145.9	0.7
2D-4	143.3	147.6	4.3
2D average	144.43	147.63	3.2
2D std dev	0.82	1.27	
3A-1	143.2	146	2.8
3A-2	141.8	144.7	2.9
3A-3	142.7	144	1.3
3A-4	142.6	144.8	2.2
3A average	142.58	144.88	2.3
3A std dev	0.58	0.83	
3B-1	145.7	148.6	2.9
3B-2	144.1	144.6	0.5
3B-3	144.8	148	3.2
3B-4	144.8	147.6	2.8
3B average	144.85	147.2	2.3

3B std dev	0.66	1.78	
3C-1	143.3	146.1	2.8
3C-2	142.7	145.9	3.2
3C-3	149.9	151.1	1.2
3C-4	145	147.5	2.5
3C average	145.23	147.65	2.4
3C std dev	3.27	2.41	
3D-1	142.3	144.8	2.5
3D-2	139.1	144.5	5.4
3D-3	141.6	143.1	1.5
3D-4	143.2	145.5	2.3
3D average	141.55	144.48	2.9
3D std dev	1.76	1.01	

Table 1: 48 Individual NDG readings with Test Area Summaries after 14 Compaction Passes

		Average values			Standard Deviations		
	Compaction passes	CPN MC-3	Troxler 23531	Average	CPN MC-3	Troxler 23531	Std. between units
WD	1	132.4333	134.1438	133.2886	3.6	3.6	1.6
DD	1	120.3854	124.4521	122.4188	3.4	3.8	3.0
%M	1	9.95881	7.990476	8.974643	0.6	0.5	1.4
WD	2	135.4354	137.6625	136.549	3.4	3.5	1.6
DD	2	123.225	127.4313	125.3282	3.2	3.3	1.8
%M	2	9.97	8.097619	9.03381	0.5	0.4	1.3
WD	4	137.9771	140.2938	139.1355	3.6	3.8	1.7
DD	4	125.6708	129.9333	127.8021	3.3	3.6	3.0
%M	4	9.883095	7.990476	8.936786	1.4	0.4	1.4
WD	14	142.7188	145.2729	143.9959	2.8	2.8	1.8
DD	14	129.9563	134.6729	132.3146	2.9	2.6	3.3
%M	14	9.907381	7.919048	8.913215	0.9	0.5	1.4

Table 2: ROB Gravel (USCS: SP)

In Table 1, the variation in the wet density readings between the two NDG units at the same data location varied from 0.5 lbs. to 5.4 lbs. The wet density readings with the same NDG around the same rod location showed variations of up to 4 lbs. Given that there were only four data points per test location, the computed standard deviation varied from 0.58 to 3.27 lbs. The standard deviation of all 48 readings at this compaction level is presented in Table 2 as 2.8 for each gauge.

The NDG measurement data in Table 2 show that the standard deviation of the individual units range from 2.8 to 3.6 for wet density, 2.6 to 3.8 for dry density and 0.4 to 0.9 for per cent moisture. The standard deviations between the two NDG units are also shown. The wet density compaction increased about 10 lbs.over the four compaction levels.

Soil 2. Crushed Stone (USCS: GP-GM), Pattersonville, NY

The material in Table 3, a **Crushed Stone**, has a USCS classification of GP-GM (i.e., poorly graded gravel with silt and sand). The material was from a quarry in Pattersonville, NY and the testing was conducted at the quarry by TransTech Personnel with TransTech units.

The NDG measurement data in Table 3 show that the standard deviation of the individual units range from 2.3 to 3.3 for wet density, 2.2 to 3.3 for dry density and 0.2 to 0.4 for per cent moisture. The standard deviations between the two NDG units are also shown. The wet density compaction increased about 10 lbs. over the three compaction levels. The Troxler gauge ceased functioning during the testing preventing data being obtained at the final compaction level.

		Average values			Standard Deviations		
	Compaction passes	CPN MC-3	Troxler 75-5594	Average	CPN MC3	Troxler 75-5594	Std. between units
WD	1	130.0313	127.3271	128.6792	2.7	3.3	2.4
DD	1	122.1667	121.1792	121.673	2.7	3.0	1.6
%M	1	6.209048	4.564286	5.386667	0.3	0.2	1.2
WD	5	143.5417	142.1708	142.8563	2.5	3.3	1.5
DD	5	134.8833	135.4167	135.15	2.4	3.1	1.4
%M	5	6.309524	4.909524	5.609524	0.3	0.3	1.0
WD	11	148.7771	146.0571	147.4171	2.3	NA	NA
DD	11	139.1896	138.5857	138.8877	2.2	NA	NA
%M	11	6.846905	5.5	6.173453	0.4	NA	NA

Table 3. Crushed Stone (USCS: GP-GM)

Soil 3. 4” Gravel Borrow (USCS: SP), ICON Materials, Auburn, WA

The material in Table 4, a **4” Gravel Borrow**, has a USCS classification of SP (i.e., poorly graded sand). The material was from a quarry in Auburn, WA and the testing was conducted at the quarry by ICON Personnel with ICON units.

		Average values			Standard Deviations		
	Compaction passes	1013 Troxler 3450	CPN MD10506170	Average	1013 Troxler 3450	CPN MD10506170	Std. between units
WD	1	126.8458	126.1938	126.5198	1.9	2.2	1.3
DD	1	120.35	118.9813	119.6657	1.9	2.1	1.5
%M	1	5.401429	6.01381	5.70762	0.2	0.3	0.4
WD	4	129.7271	128.3813	129.0542	2.2	2.2	1.4
DD	4	123.1104	121.1479	122.1292	2.1	2.2	1.7
%M	4	5.349524	5.939524	5.644524	0.3	0.2	0.5
WD	8	132.0313	130.6875	131.3594	2.0	1.6	1.3
DD	8	125.1667	123.4813	124.324	2.2	1.5	1.6
%M	8	5.262143	5.922143	5.592143	0.2	0.4	0.5

Table 4. 4” Gravel Borrow (USCS: SP)

The NDG measurement data in Table 4 show that the standard deviation of the individual units range from 1.6 to 2.2 for wet density, 1.5 to 2.1 for dry density and 0.2 to 0.4 for per cent moisture. The standard deviations between the two NDG units are also shown.

Soil 4. 1 ¼" Crushed Base Course (USCS: GP-GM), ICON Materials, Auburn, WA

The material in Table 5, a **1 ¼" Crushed Base Course**, has a USCS classification of GP-GM (i.e., poorly graded gravel with silt and sand). The material was from a quarry in Auburn, WA and the testing was conducted at the quarry by ICON Personnel with ICON units.

		Average values			Standard Deviations		
	Compaction passes	1013 Troxler 3450	CPN MD10506170	Average	1013 Troxler 3450	CPN: MD10506170	Std. between units
WD	1	121.3396	118.6771	120.0084	2.2	1.5	2.0
DD	1	117.075	113.8604	115.4677	2.3	1.5	2.3
%M	1	3.672619	4.321429	3.997024	0.2	0.3	0.5
WD	4	125.4375	122.9167	124.1771	1.4	1.4	1.9
DD	4	120.9146	117.8438	119.3792	1.4	1.4	2.3
%M	4	3.764048	4.307857	4.035953	0.3	0.2	0.4
WD	10	131.3188	129.7708	130.5448	2.5	1.5	1.6
DD	10	126.4813	124.4229	125.4521	2.6	1.5	1.9
%M	10	3.826667	4.402619	4.114643	0.2	0.1	0.4

Table 5. 1 ¼" Crushed Base Course (USCS: GP-GM)

The NDG measurement data in Table 5 show that the standard deviation of the individual units range from 1.4 to 2.5 for wet density, 1.4 to 2.6 for dry density and 0.1 to 0.3 for per cent moisture. The standard deviations between the two NDG units are also shown. The wet density compaction increased about 5 lbs. over the three compaction levels.

Soil 5. Red Silt Clay (USCS: CL), Qore, Jefferson, GA

The material in Table 6, a **Red Silt Clay**, has a USCS classification of CL (i.e., lean clay). The material was from a quarry in Jefferson, GA and the testing was conducted at the quarry by Qore Personnel with Qore units.

The NDG measurement data in Table 6 show that the standard deviation of the individual units range from 0.6 to 2.5 for wet density, 0.8to 2.1 for dry density and 0.6 to 1.0 for per cent moisture. The standard deviations between the two NDG units are also shown. The wet density compaction increased about 7 lbs. over the three compaction levels.

		Average values			Standard Deviations		
	Compaction passes	Humbolt 102 Model 5001	Troxler 6964	Average	Humbolt 102 Model 5001	Troxler 6964	Std. between units
WD	1	117.4396	118.2771	117.8584	2.5	2.5	2.0
DD	1	92.51458	93.03958	92.77708	1.8	2.1	1.5
%M	1	27.22143	27.0881	27.15477	0.7	1.0	0.7
WD	4	123.0333	123.7438	123.3886	0.9	0.9	0.8
DD	4	95.69167	96.26667	95.97917	0.9	0.8	0.7
%M	4	28.53571	28.49286	28.51429	0.6	0.6	0.5
WD	12	124.8438	125.8563	125.3501	0.6	0.6	0.8
DD	12	96.91667	97.83125	97.37396	0.8	0.8	0.8
%M	12	28.72857	28.62143	28.675	0.6	0.6	0.5

Table 6. Red Silt Clay (USCS: CL)

Soil 6. Graded Aggregate Base (USCS: GP-GM), Qore, Jefferson, GA

The material in Table 7, a **Graded Aggregate Base**, has a USCS classification of GP-GM (i.e., poorly graded gravel with silt and sand). The material was from a quarry in Jefferson, GA and the testing was conducted at the quarry by Qore Personnel with Qore units.

The NDG measurement data in Table 7 show that the standard deviation of the individual units range from 1.1 to 3.6 for wet density, 1.5 to 2.1 for dry density and 0.2 to 0.4 for per cent moisture. The standard deviations between the two NDG units are also shown. The wet density compaction increased over 18 lbs. over the three compaction levels.

		Average values			Standard Deviations		
	Compaction passes	CPN 39576	Troxler 38379	Average	CPN 39576	Troxler 38379	Std. between units
WD	1	121.2688	122.1188	121.6938	3.6	3.4	2.3
DD	1	119.1042	119.8521	119.4782	3.7	3.4	2.4
%M	1	1.82619	1.82381	1.825	0.2	0.2	0.1
WD	3	126.7083	127.7729	127.2406	1.7	1.5	1.3
DD	3	124.4854	125.4042	124.9448	1.7	1.5	1.3
%M	3	1.8	1.892857	1.846429	0.1	0.1	0.1
WD	7	139.9708	140.2563	140.1136	1.1	1.4	0.8
DD	7	132.3	132.4583	132.3792	1.1	1.4	0.7
%M	7	5.878571	5.916667	5.897619	0.2	0.3	0.2

Table 7. Graded Aggregate Base (USCS: GP-GM)

Soil 7. Red Sand with Rock (USCS: GW-GM), Oklahoma

The material in Table 8, a **Red Sand with Rock**, has a USCS classification of GW-GM (i.e., well graded gravel with silt and sand). The material was from a quarry in Oklahoma and the testing was conducted at the quarry by xxx, a local soil testing contractor.

		Average values	Standard Deviations
	Compaction passes	CPN	CPN
WD	1	117.7938	2.1
DD	1	110.3708	1.8
%M	1	6.547619	0.6
WD	3	123.9104	2.0
DD	3	115.8146	1.7
%M	3	6.82143	0.4
WD	9	128.333	1.9
DD	9	120.413	2.4
%M	9	6.98095	0.4

Table 8. Red Sand with Rock (USCS: GW-GM)

For this test sequence only one NDG was available. The NDG measurement data in Table 8 show that the standard deviation of the individual unit range from 1.9 to 2.1 for wet density, 1.7 to 1.9 for dry density and 0.4 to 0.6 for per cent moisture. The standard deviations between the two NDG units are also shown. The wet density compaction increased a little over 10 lbs. for the three compaction levels.

Soil 8. Red Sandy Clay (USCS: CL-ML), Clough Harbour, Texas

The material in Table 9, a **Red Sandy Clay**, has a USCS classification of CL-ML (i.e., silty clay).

The NDG measurement data in Table 8 show that the standard deviation of the individual units range from 1.6 to 2.6 for wet density, 1.5 to 2.6 for dry density and 0.5 to 0.9 for per cent moisture. The standard deviations between the two NDG units are also shown. The wet density compaction increased about 20 lbs. over the three compaction levels. During the third compaction level (i.e., Compaction Passes = 4), one of the NDGs broke, hence it was not appropriate to calculate the standard deviation between the NDGs for this compaction level.

		Average values			Standard Deviations		
	Compaction passes	Humbolt 102	Troxler 6964	Average	Humbolt 102	Troxler 6964	Std. between units
WD	1	98.40872	98.95208	98.6804	2.6	2.6	2.0
DD	1	86.12313	88.58333	87.35323	2.5	2.6	2.4
%M	1	14.01262	11.70476	12.85869	0.7	0.9	1.7
WD	2	119.1021	119.1958	119.149	1.9	1.9	1.4
DD	2	104.36	106.2021	105.2811	1.8	1.6	1.6
%M	2	14.1769	12.16667	13.17179	0.5	0.8	1.4
WD	4	127.9188	128.7271	128.323	1.6	NA	NA
DD	4	112.2438	114.925	113.5844	1.5	NA	NA
%M	4	13.9875	12.00209	12.9948	0.5	NA	NA

Table 9. Red Sandy Clay (USCS: CL-ML)

Conclusion

Table 10 is a summary of the average NDG data standard deviations discussed above. It would be expected that the standard deviation at a single location (see Table 1 for example) would be less than that for a complete compaction level since some soil variation would be expected over the entire test mat. On six of the eight tested materials, the wet density standard deviation between the NDGs (i.e., Column 3) was less than the wet density standard deviation for a single location (i.e., Column 1). However, only four of the eight tested materials have a dry density standard deviation between the NDGs (i.e., Column 3) that was less than the dry density standard deviation for a single location (i.e., Column 1). And, only two of the eight tested materials had a percent moisture standard deviation between the NDGs (i.e., Column 3) that was less than the percent moisture standard deviation for a single location (i.e., Column 1). From this study, it was seen that the NDG unit-to-unit variability was three times greater for the measurement of percent moisture than for the measurement of wet density. As a result of the increased variability in percent moisture from unit-to-unit, the unit-to-unit variability of dry density is also affected.

For **Red Sand w/ Rock** material in Table 10 below it was not appropriate (NA) to calculate the 'Standard Deviation between NDGs' since at the time of the, test only one NDG was available. The bottom line is that the average wet density standard deviation for all of the units, on all of the soils is:

- 2.0 lbs/ft^3 for all NDGs on all soils at a single location
- 4.4 lbs/ft^3 for a all NDGs on all soils at a single compaction level
- 1.6 lbs/ft^3 for between NDG pairs on all soils at a single location

		Average NDG Standard Deviation for Single Location	Average NDG Standard Deviation for Compaction Level	Standard Deviation between NDGs at a Single Location
Wet Density Standard Deviation (lb/ft^3)	Crushed Stone	2.7	7.7	2.0
	ROB Gravel	1.9	3.4	1.7
	4" Gravel Borrow	2.0	3.1	1.3
	1 ¼" Crushed Base Course	1.7	3.3	1.8
	Red Silt Clay	1.3	2.3	1.2
	Graded Aggregate Base	2.1	2.5	1.5
	Red Sand w/ Rock	2.0	4.0	NA
	Red Sandy Clay	2.0	6.2	1.7
Dry Density Standard Deviation (lb/ft^3)	Crushed Stone	2.6	6.6	1.5
	ROB Gravel	2.0	3.3	2.8
	4" Gravel Borrow	2.0	3.0	1.6
	1 ¼" Crushed Base Course	1.8	3.2	2.2
	Red Silt Clay	1.2	1.7	1.0
	Graded Aggregate Base	2.2	2.4	1.5
	Red Sand w/ Rock	2.0	3.4	NA
	Red Sandy Clay	1.9	5.5	2.0
Percent Moisture Standard Deviation (%)	Crushed Stone	0.3	0.9	1.1
	ROB Gravel	0.5	0.7	1.4
	4" Gravel Borrow	0.3	0.4	0.5
	1 ¼" Crushed Base Course	0.2	0.4	0.4
	Red Silt Clay	0.7	1.1	0.6
	Graded Aggregate Base	0.2	0.3	0.1
	Red Sand w/ Rock	0.5	1.1	NA
	Red Sandy Clay	0.7	0.9	1.6

Table 10. NDG Data Summary

APPENDIX E

SDG Controlled Field Precision Test Procedure and Results

Appendix E. SDG Controlled Field Precision Test Procedure and Results

As part of the ASTM standard requirement, test instruments have to have a precision and bias statement. Since there is not an absolute standard for soils, only an instrument precision test and statement can be provided for the SDG. The procedure used in the testing is provided below.

The SDG precision testing is to be completed after all of the data has been collected on each the controlled compaction test beds. In the ASTM Spec E691-99 it calls for no less than six laboratories for each material, in TransTech's case it would be six instruments on each material tested. In this test, four non-TransTech employees are to participate in the necessary data collection for the ASTM specification. The three ASTM tests which will be conducted are covered below. The data collection work sheets for the three ASTM tests are also attached.

Test 1 – Instrument Repeatability

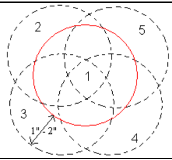
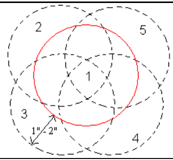
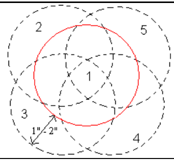
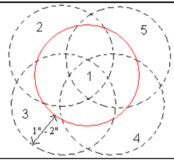
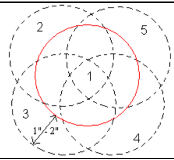
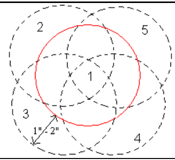
Since there is no standard for soils, this test is designed to determine instrument precision or repeatability only. Each operator/unit will take four sets of five measurements each (20 total), all in the <u>same location</u>, only picking up in-between each measurement and placing it back in the same spot. Each of the four operators/units can conduct this test at a different location.

	1 - 5 Pick up in-between each measurement and place back in the same spot
1	**A coeff:**
	B coeff:
2	**A coeff:**
	B coeff:
3	**A coeff:**
	B coeff:
4	**A coeff:**
	B coeff:

Test 2 – Instrument Variation

This test is designed to determine the instrument variation in readings at different locations (samples) with the same operator. At six locations designated, each operator/unit will take two sets of "pattern of five" measurements, for a total of twelve sets. The two sets at each individual location will be taken on the same measurement volume.

Location 1	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**

					
A coeff:	**A coeff:**	**A coeff:**	**A coeff:**	**A coeff:**	**A coeff:**
B coeff:	**B coeff:**	**B coeff:**	**B coeff:**	**B coeff:**	**B coeff:**
A coeff:	**A coeff:**	**A coeff:**	**A coeff:**	**A coeff:**	**A coeff:**
B coeff:	**B coeff:**	**B coeff:**	**B coeff:**	**B coeff:**	**B coeff:**

Test 3 – Operator Variation

This test is designed to investigate variation introduced by operator operation. Therefore, the same instrument will be used to measure the same sample (spot) with four different operators. Three operators will take one unit and replicate the twenty measurements at the same location as the original operator took in Test 1.

	1 - 5 Pick up in-between each measurement and place back in the same spot	1 - 5 Pick up in-between each measurement and place back in the same spot	1 - 5 Pick up in-between each measurement and place back in the same spot	1 - 5 Pick up in-between each measurement and place back in the same spot
1	**A coeff:** *completed in Test 1*	**A coeff:**	**A coeff:**	**A coeff:**
	B coeff: *completed in Test 1*	**B coeff:**	**B coeff:**	**B coeff:**
2	**A coeff:** *completed in Test 1*	**A coeff:**	**A coeff:**	**A coeff:**
	B coeff: *completed in Test 1*	**B coeff:**	**B coeff:**	**B coeff:**
3	**A coeff:** *completed in Test 1*	**A coeff:**	**A coeff:**	**A coeff:**
	B coeff: *completed in Test 1*	**B coeff:**	**B coeff:**	**B coeff:**
4	**A coeff:** *completed in Test 1*	**A coeff:**	**A coeff:**	**A coeff:**
	B coeff: *completed in Test 1*	**B coeff:**	**B coeff:**	**B coeff:**
	Operator:	**Operator:**	**Operator:**	**Operator:**

2.0 Controlled Field Test ASTM Test 1

Four operators, each with a different SDG unit, took four sets of five measurements, each at a different location, only picking up in-between each of the twenty measurements and placing it back in the same spot.

This test was designed to show the usual density and moisture spread of a measurement using several instruments, operators and test locations for multiple soil types. Tables 2-1 – 2-6 are the individual standard deviations seen by each unit for density and moisture at its test location, for six different soil types. Table 2-7 is a summary of the materials tested and the average standard deviations seen by the four SDGs.

On the 4" Gravel Borrow (USCS: SP) material tested in Washington State, Table 2-1, the SDG had an average wet density, volumetric moisture, dry density and percent moisture standard deviation of 1.9 lb/ft^3, 0.5%, 1.4 lb/ft^3 and 0.3%, respectively. On the second material tested in Washington State, 1 ¼" Crushed Base Course (USCS: GP-GM), Table 2-2, the SDG had an average wet density, volumetric moisture, dry density and percent moisture standard deviation of 1.7 lb/ft^3, 0.4%, 1.3 lb/ft^3 and 0.2%, respectively. On this test day, SDG SN 8 was measuring on average 15 to 20 lb/ft^3 higher than the other instruments, therefore, the numbers in parentheses are the standard deviations of the measurements without SDG SN 8 data. Once back at TransTech Systems, it was found that a couple of the instruments were damaged during the shipping process, this is thought to be the reason for the high readings with SDG SN 8. The average wet density, volumetric moisture, dry density and percent moisture standard deviations without SDG SN 8 are 1.1 lb/ft^3, 0.2%, 0.8 lb/ft^3 and 0.1% respectively.

At the next test location in Jefferson, Georgia, Table 2-3, the SDG had an average wet density, volumetric moisture, dry density and percent moisture standard deviation on Silt Clay (USCS: CL) of 0.3 lb/ft^3, 0.1%, 0.2 lb/ft^3 and 0.03%, respectively. On the second material tested in Georgia, Graded Aggregate Base (USCS: GP-GM), Table 2-4, the SDG had an average wet density, volumetric moisture, dry density and percent moisture standard deviation of 0.8 lb/ft^3, 0.3%, 0.4 lb/ft^3 and 0.2%, respectively.

At the final locations in Oklahoma and Texas, the SDG had an average wet density, volumetric moisture, dry density and percent moisture standard deviation on Red Sand with Rock (USCS: GW-GM), Table 2-5, of 1.3 lb/ft^3, 0.3%, 1.0 lb/ft3 and 0.2%, respectively. On the second material tested in Oklahoma/Texas, Red Sandy Clay (USCS: CL-ML), Table 2-6, the SDG had an average wet density, volumetric moisture, dry density and percent moisture standard deviation of 1.0 lb/ft^3, 0.2%, 0.8 lb/ft^3 and 0.1%, respectively.

Summarized in Table 2-7, ASTM Test 1, for each of the six soil types measured upon, the average wet density standard deviation was less than 2.0 lb/ft^3, the average volumetric moisture content standard deviation was less than 0.5%, the average dry density standard deviation was less than 1.5 lb/ft^3 and the average percent moisture content standard deviation was 0.3% or less.

Location: Icon Materials, Auburn, Washington
Material: 4” Gravel Borrow (USCS: SP)

	SN 1	SN 4	SN 8	SN 16	Average
Wet Density STD (lb/ft^3)	1.584	2.171	0.729	3.240	1.931
Vol. Moist STD (%)	0.372	0.571	0.171	0.827	0.485
Dry Density STD (lb/ft^3)	1.212	1.603	0.558	2.413	1.447
Percent Moist STD (%)	0.261	0.373	0.111	0.519	0.316

Table 2-1. 4” Gravel Borrow (USCS: SP)

Location: Icon Materials, Auburn, Washington

Material: 1 ¼” Crushed Base Course (USCS: GP-GM)

	SN 1	SN 4	SN 8	SN 16	Average (w/o SN 8)
Wet Density STD (lb/ft^3)	0.431	0.506	4.043	1.689	1.667 (1.060)
Vol. Moist STD (%)	0.081	0.102	0.886	0.346	0.354 (0.214)
Dry Density STD (lb/ft^3)	0.350	0.404	3.157	1.343	1.313 (0.846)
Percent Moist STD (%)	0.047	0.062	0.404	0.182	0.174 (0.115)

Table 2-2. 1 ¼” Crushed Base Course (USCS: GP-GM)

Location: Qore, Jefferson, Georgia
Material: Red Silt Clay (USCS: CL)

	SN 3	SN 4	SN 5	SN 8	Average
Wet Density STD (lb/ft^3)	0.537	0.174	0.198	0.245	0.288
Vol. Moist STD (%)	0.158	0.046	0.053	0.064	0.080
Dry Density STD (lb/ft^3)	0.379	0.128	0.145	0.181	0.208
Percent Moist STD (%)	0.072	0.017	0.020	0.023	0.033

Table 2-3. Red Silt Clay (USCS: CL)

Location: Qore, Jefferson, Georgia
Material: Graded Aggregate Base (USCS: GP-GM)

	SN 3	SN 4	SN 5	SN 8	Average
Wet Density STD (lb/ft^3)	0.652	0.663	1.114	0.571	0.750
Vol. Moist STD (%)	0.276	0.282	0.468	0.250	0.319
Dry Density STD (lb/ft^3)	0.375	0.381	0.646	0.321	0.431
Percent Moist STD (%)	0.185	0.198	0.330	0.172	0.222

Table 2-4. : Graded Aggregate Base (USCS: GP-GM)

Location: Clough Harbour, Oklahoma/Texas
Material: Red Sand with Rock (USCS: GW-GM)

	SN 3	SN 4	SN 5	SN 8	Average
Wet Density STD (lb/ft^3)	0.578	1.139	2.958	0.616	1.323
Vol. Moist STD (%)	0.125	0.291	0.643	0.146	0.301
Dry Density STD (lb/ft^3)	0.454	0.848	2.315	0.471	1.022
Percent Moist STD (%)	0.087	0.223	0.470	0.120	0.225

Table 2-5. Red Sand with Rock (USCS: GW-GM)

Location: Clough Harbour, Oklahoma/Texas
Material: Red Sandy Clay (USCS: CL-ML)

	SN 3	SN 4	SN 5	SN 8	Average
Wet Density STD (lb/ft^3)	1.065	No Data	1.002	0.888	0.985
Vol. Moist STD (%)	0242	No Data	0.214	0.202	0.219
Dry Density STD (lb/ft^3)	0.824	No Data	0.788	0.687	0.766
Percent Moist STD (%)	0.141	No Data	0.117	0.112	0.123

Table 2-6. Red Sandy Clay (USCS: CL-ML)

Location: All
Material: All

USCS:	**SP**	**GP-GM (w/o SN 8)**	**CL**	**GP-GM**	**GW-GM**	**CL-ML**
Wet Density STD (lb/ft^3)	1.931	1.667 (1.060)	0.288	0.750	1.323	0.985
Vol. Moist STD (%)	0.485	0.354 (0.214)	0.080	0.319	0.301	0.219
Dry Density STD (lb/ft^3)	1.447	1.313 (0.846)	0.208	0.431	1.022	0.766
Percent Moist STD (%)	0.316	0.174 (0.115)	0.033	0.222	0.225	0.123

Table 2-7. Summary of Six Soil Types and Average Standard Deviations (Density and Moisture)

3.0 Controlled Field Test ASTM Test 2

Four operators, each with a different SDG unit, took two sets of measurements at six locations. For each measurement set, the standard clover-leave pattern of five was used. This test was designed to show the density and moisture spread of four instruments with four operators on several soil types. This test was repeated at three different locations and two soil types at each location. The results are presented below.

Tables 3-1 and 3-2 display the data and standard deviations of the SDG data on the 4” gravel borrow material. Table 3-1 displays the average wet density, dry density, volumetric moisture and percent moisture measurements taken by the instruments at the six locations. Table 3-2 displays the standard deviations of the four measurements at the six locations. The seventh column in the table is the average standard deviations, for the six locations, for the density and moisture measurements. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 5.3 lb/ft^3, 1.4%, 3.9 lb/ft^3 and 1.0% respectively.

Location: Icon Materials, Auburn, Washington

Material: 4” Gravel Borrow (USCS: SP)

		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Wet Density (lb/ft^3)	**SN 1**	121.3	125.4	122.6	121.6	120.9	122.0
	SN 4	127.2	130.3	126.3	125.0	129.2	129.0
	SN 8	124.6	131.4	125.9	125.0	129.6	126.7
	SN 16	133.1	138.4	135.3	132.6	136.7	133.8
Vol. Moisture (%)	**SN 1**	6.1	7.1	6.5	6.2	6.1	6.3
	SN 4	7.6	8.3	7.4	7.1	8.1	8.0
	SN 8	7.1	8.7	7.4	7.2	8.3	7.6
	SN 16	9.4	10.6	9.9	9.2	10.2	9.4
Dry Density (lb/ft^3)	**SN 1**	115.1	118.3	116.1	115.4	114.8	115.7
	SN 4	119.6	122.0	118.9	118.0	121.1	121.0
	SN 8	117.5	122.6	118.5	117.8	121.3	119.1
	SN 16	123.7	127.8	125.4	123.4	126.5	124.4
Percent Moisture (%)	**SN 1**	5.3	6.0	5.6	5.4	5.3	5.4
	SN 4	6.3	6.8	6.2	6.0	6.7	6.6
	SN 8	6.1	7.1	6.2	6.1	6.8	6.4
	SN 16	7.6	8.3	7.9	7.5	8.1	7.6

Table 3-1. SDG Data on 4” Gravel Borrow (USCS:SP)

	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Avg.
Wet Density STD (lb/ft^3)	5.0	5.4	5.4	4.6	6.5	4.9	***5.3***
Vol. Moisture STD (%)	1.4	1.4	1.4	1.3	1.7	1.3	***1.4***
Dry Density STD (lb/ft^3)	3.6	3.9	4.0	3.4	4.8	3.6	***3.9***
Percent Moisture STD (%)	0.9	0.9	1.0	0.9	1.1	0.9	***1.0***

Table 3-2. Standard Deviation Summary of SDG on 4” Gravel Borrow (USCS: SP)

Tables 3-3 and 3-4 display the data and standard deviations of the SDG data on the 1 ¼” crushed base course material. Table 3-3 displays the average wet density, dry density, volumetric moisture and percent moisture measurements taken by the instruments at the six locations. Table 3-4 displays the standard deviations of the measurements at the six locations. On this test day, SDG SN 8 was measuring on average 15 to 20 lb/ft^3 higher than the other instruments, therefore, the numbers in parentheses are the standard deviations of the measurements without SDG SN 8 data. Once back at TransTech Systems, it was found that a couple of the instruments were damaged during the shipping process, this is thought to be the reason for the high reading with SDG SN 8. The seventh column in the table is the average standard deviation, for the six locations, for the density and moisture measurements. The average wet density, volumetric moisture, dry density and percent moisture standard deviations without SDG SN 8 are 6.5 lb/ft^3, 1.5%, 5.0 lb/ft^3 and 0.9% respectively. (SDG SN 8 data was used in ASTM Test 1 since the standard deviation within each unit was being investigated. In ASTM Test 2, the absolute answers of the four instruments are being compared; therefore SN 8 is no longer comparable to other instruments.)

Location: Icon Materials, Auburn, Washington
Material: 1 ¼" Crushed Base Course (USCS: GP-GM)

		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Wet Density (lb/ft^3)	**SN 1**	123.4	121.3	125.2	126.5	127.2	130.8
	SN 4	129.6	128.9	130.4	133.9	132.2	136.0
	SN 8	151.5	147.0	151.6	149.8	142.8	153.0
	SN 16	138.3	134.2	136.6	141.9	138.8	142.0
Vol. Moisture (%)	**SN 1**	7.1	6.6	7.4	7.7	7.8	8.5
	SN 4	8.4	8.2	8.5	9.2	8.8	9.6
	SN 8	13.3	12.4	13.4	12.8	11.3	13.5
	SN 16	10.5	9.7	10.1	11.2	10.5	11.2
Dry Density (lb/ft^3)	**SN 1**	116.4	114.7	117.8	118.9	119.4	122.3
	SN 4	121.3	120.7	121.9	124.7	123.4	126.4
	SN 8	138.2	134.6	138.3	137.0	131.5	139.4
	SN 16	127.9	124.5	126.5	130.7	128.2	130.8
Percent Moisture (%)	**SN 1**	6.1	5.8	6.3	6.5	6.5	7.0
	SN 4	6.9	6.8	7.0	7.4	7.2	7.6
	SN 8	9.6	9.2	9.7	9.4	8.6	9.7
	SN 16	8.2	7.8	8.0	8.6	8.2	8.5

Table 3-3. SDG Data on 1 ¼" Crushed Base Course (USCS: GP-GM)

	Location 1	**Location 2**	**Location 3**	**Location 4**	**Location 5**	**Location 6**	**Avg.**(w/o8)
Wet Density STD (lb/ft^3)	12.2(7.5)	10.8(6.5)	11.4(5.7)	10.1(7.7)	6.9(5.8)	9.5(5.6)	***10.1***(6.5)
Vol. Moisture STD (%)	2.7(1.7)	2.5(1.5)	2.6(1.4)	2.3(1.8)	1.6(1.4)	2.2(1.3)	***2.3***(1.5)
Dry Density STD (lb/ft^3)	9.4(5.8)	8.4(5.0)	8.9(4.4)	7.8(5.9)	5.3(4.4)	7.3(4.3)	***7.8***(5.0)
Percent Moisture STD (%)	1.6(1.1)	1.5(1.0)	1.5(0.9)	1.3(1.1)	0.9(0.8)	1.2(0.8)	***1.3***(0.9)

Table 3-4. Standard Deviation Summary of SDG on 1 ¼" Crushed Base Course (USCS: GP-GM)

Tables 3-5 and 3-6 display the data and standard deviations of the SDG data on the red silt clay material. Table 3-5 displays the average wet density, dry density, volumetric moisture and percent moisture measurements taken by the instruments at the six locations. Table 3-6 displays the standard deviations of the measurements at the six locations. The seventh column in the table is the average standard deviation, for the six locations, for the density and moisture measurements. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 0.6 lb/ft^3, 0.2%, 0.4 lb/ft^3 and 0.1% respectively.

Location: Qore, Jefferson, Georgia
Material: Red Silt Clay (USCS: CL)

		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Wet Density (lb/ft^3)	**SN 3**	126.5	127.8	126.2	129.3	127.5	127.7
	SN 4	127.7	127.7	126.8	130.4	128.4	128.2
	SN 5	125.5	127.6	125.9	128.6	126.5	126.5
	SN 8	126.8	127.8	126.0	128.8	127.0	127.0
Vol. Moisture (%)	**SN 3**	23.0	23.4	22.9	23.8	23.3	23.4
	SN 4	23.4	23.4	23.1	24.1	23.6	23.5
	SN 5	22.7	23.3	22.8	23.6	23.0	23.0
	SN 8	23.2	23.4	22.9	23.7	23.2	23.2
Dry Density (lb/ft^3)	**SN 3**	103.5	104.4	103.3	105.6	104.2	104.4
	SN 4	104.3	104.3	103.7	106.3	104.8	104.7
	SN 5	102.8	104.4	103.1	105.1	103.5	103.5
	SN 8	103.6	104.4	103.0	105.1	103.8	103.8
Percent Moisture (%)	**SN 3**	22.3	22.4	22.2	22.5	22.4	22.4
	SN 4	22.4	22.4	22.3	22.7	22.5	22.5
	SN 5	22.1	22.3	22.1	22.4	22.2	22.2
	SN 8	22.3	22.5	22.3	22.5	22.4	22.4

Table 3-5. SDG Data on Red Silt Clay (USCS: CL)

	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Avg.
Wet Density STD (lb/ft^3)	0.9	0.1	0.4	0.8	0.8	0.7	***0.6***
Vol. Moisture STD (%)	0.3	0.1	0.1	0.2	0.2	0.2	***0.2***
Dry Density STD (lb/ft^3)	0.6	0.1	0.3	0.6	0.6	0.5	***0.4***
Percent Moisture STD (%)	0.1	0.1	0.1	0.1	0.1	0.1	***0.1***

Table 3-6. Standard Deviation Summary of SDG on Red Silt Clay (USCS: CL)

Tables 3-7 and 3-8 display the data and standard deviations of the SDG data on the Georgia graded aggregate base material. Table 3-7 displays the average wet density, dry density, volumetric moisture and percent moisture measurements taken by the instruments at the six locations. Table 3-8 displays the standard deviations of the measurements at the six locations. The seventh column in the table is the average standard deviation, for the six locations, for the density and moisture measurements. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 0.9 lb/ft^3, 0.5%, 0.5 lb/ft^3 and 0.3% respectively.

Tables 3-9 and 3-10 display the data and standard deviations of the SDG data on the Texas red sand with rock material. Table 3-9 displays the average wet density, dry density, volumetric moisture and percent moisture measurements taken by the instruments at the six locations. Table 3-10 displays the standard deviations of the measurements at the six locations. The seventh column in the table is the average standard deviation, for the six locations, for the density and moisture measurements. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 1.9 lb/ft^3, 0.4%, 1.5 lb/ft^3 and 0.3% respectively.

Location: Qore, Jefferson, Georgia
Material: Graded Aggregate Base (USCS: GP-GM)

		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Wet Density (lb/ft^3)	**SN 3**	135.9	139.2	141.5	140.6	138.4	141.2
	SN 4	137.5	139.6	142.6	141.5	139.1	141.8
	SN 5	135.1	137.9	140.5	139.0	137.1	139.8
	SN 8	136.9	139.5	142.3	141.2	138.5	141.2
Vol. Moisture (%)	**SN 3**	7.5	8.9	9.9	9.5	8.6	9.8
	SN 4	8.3	9.2	10.5	10.0	9.0	10.1
	SN 5	7.2	8.3	9.4	8.8	8.0	9.1
	SN 8	8.1	9.2	10.4	9.9	8.8	9.9
Dry Density (lb/ft^3)	**SN 3**	128.3	130.2	131.6	131.1	129.8	131.4
	SN 4	129.2	130.4	132.2	131.5	130.1	131.7
	SN 5	127.9	129.6	131.1	130.2	129.1	130.6
	SN 8	128.8	130.3	131.9	131.3	129.8	131.3
Percent Moisture (%)	**SN 3**	5.9	6.9	7.5	7.3	6.6	7.4
	SN 4	6.4	7.0	7.9	7.6	6.9	7.7
	SN 5	5.6	6.4	7.2	6.7	6.2	7.0
	SN 8	6.3	7.1	7.9	7.6	6.7	7.5

Table 3-7. SDG Data on Graded Aggregate Base (USCS: GP-GM)

	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Avg.
Wet Density STD (lb/ft^3)	1.1	0.8	1.0	1.1	0.9	0.9	***0.9***
Vol. Moisture STD (%)	0.5	0.4	0.5	0.6	0.4	0.4	***0.5***
Dry Density STD (lb/ft^3)	0.5	0.4	0.5	0.6	0.4	0.4	***0.5***
Percent Moisture STD (%)	0.4	0.3	0.3	0.4	0.3	0.3	***0.3***

Table 3-8. Standard Deviation Summary of SDG Graded Aggregate Base (USCS: GP-GM)

Location: Clough Harbour, Oklahoma/Texas
Material: Red Sand with Rock (USCS: GW-GM)

		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Wet Density (lb/ft^3)	**SN 3**	112.3	127.0	114.1	111.0	113.9	113.6
	SN 4	114.4	125.8	119.5	113.8	115.0	118.0
	SN 5	111.7	125.1	118.3	117.8	111.4	113.5
	SN 8	112.0	124.1	116.4	116.6	113.8	113.1
Vol. Moisture (%)	**SN 3**	4.4	7.6	4.8	4.1	4.8	4.7
	SN 4	5.0	7.5	6.1	4.8	5.1	5.7
	SN 5	4.4	7.3	5.8	5.7	4.3	4.8
	SN 8	4.6	7.2	5.5	5.6	5.0	4.8
Dry Density (lb/ft^3)	**SN 3**	107.9	119.4	109.3	106.9	109.1	108.9
	SN 4	109.4	118.3	113.4	109.0	109.9	112.3
	SN 5	107.3	117.8	112.5	112.1	107.1	108.7
	SN 8	107.4	116.9	110.9	111.0	108.8	108.3
Percent Moisture (%)	**SN 3**	4.1	6.4	4.4	3.9	4.4	4.3
	SN 4	4.6	6.3	5.3	4.4	4.6	5.1
	SN 5	4.1	6.2	5.2	5.1	4.0	4.4
	SN 8	4.3	6.2	5.0	5.0	4.5	4.5

Table 3-9. SDG Data on Red Sand with Rock (USCS: GW-GM)

	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Avg.
Wet Density STD (lb/ft^3)	1.2	1.2	2.4	3.0	1.5	2.3	***1.9***
Vol. Moisture STD (%)	0.3	0.2	0.6	0.7	0.3	0.5	***0.4***
Dry Density STD (lb/ft^3)	1.0	1.0	1.8	2.3	1.2	1.8	***1.5***
Percent Moisture STD (%)	0.2	0.1	0.4	0.6	0.3	0.4	***0.3***

Table 3-10. Standard Deviation Summary of Red Sand with Rock (USCS: GW-GM)

Tables 3-11 and 3-12 display the data and standard deviations of the SDG data on the Texas red sandy clay material. The battery died for SDG SN 4 during the ASTM testing, therefore it was not included in the analysis. Table 3-11 displays the average wet density, dry density, volumetric moisture and percent moisture measurements taken by the instruments at the six locations. Table 3-12 displays the standard deviations of the measurements at the six locations. The seventh column in the table is the average standard deviation, for the six locations, for the density and moisture measurements. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 4.0 lb/ft^3, 1.0%, 3.0 lb/ft^3 and 0.7% respectively.

<u>Location</u>: Clough Harbour, Oklahoma/Texas
<u>Material</u>: Red Sandy Clay (USCS: CL-ML)

		Location 1	Location 2	Location 3	Location 4	Location 5	Location 6
Wet Density (lb/ft^3)	**SN 3**	119.1	121.6	107.2	124.8	109.2	110.5
	SN 4	**No Data**					
	SN 5	116.8	121.6	113.9	125.5	106.3	115.1
	SN 8	119.3	124.9	111.1	114.7	110.5	128.1
Vol. Moisture (%)	**SN 3**	12.0	12.3	9.0	13.3	9.8	9.8
	SN 4	**No Data**					
	SN 5	11.7	12.5	10.4	13.6	9.3	10.9
	SN 8	12.4	13.5	10.4	11.2	10.4	14.4
Dry Density (lb/ft^3)	**SN 3**	107.1	109.3	98.2	111.5	99.4	100.6
	SN 4	**No Data**					
	SN 5	105.2	109.1	103.5	111.9	97.0	104.2
	SN 8	106.9	111.4	100.7	103.6	100.1	113.7
Percent Moisture (%)	**SN 3**	11.2	11.3	9.1	11.9	9.8	9.8
	SN 4	**No Data**					
	SN 5	11.1	11.5	10.0	12.1	9.6	10.5
	SN 8	11.6	12.2	10.3	10.8	10.4	12.7

Table 3-11. SDG Data on Red Sandy Clay (USCS: CL-ML)

	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Avg.
Wet Density STD (lb/ft^3)	1.4	1.9	3.4	6.0	2.2	9.1	***4.0***
Vol. Moisture STD (%)	0.4	0.7	0.8	1.3	0.6	2.4	***1.0***
Dry Density STD (lb/ft^3)	1.1	1.3	2.7	4.7	1.6	6.7	***3.0***
Percent Moisture STD (%)	0.3	0.5	0.6	0.7	0.4	1.5	***0.7***

Table 3-12. Standard Deviation Summary of Red Sandy Clay (USCS: CL-ML)

ASTM Test 2 is summarized in Table 3-13 for each of the six soil types measured upon, the average wet density standard deviation with four instruments and four operators was less than or equal to 6.5 lb/ft^3. The average volumetric moisture content standard deviation with four instruments and four operators was less than or equal to 1.5%. The average dry density standard deviation with four instruments and four operators was less than or equal to 5.0 lb/ft^3. The average percent moisture standard deviation with four instruments and four operators was less than or equal to 1.0%.

Location: All
Material: All

USCS:	SP	GP-GM	CL	GP-GM	GW-GM	CL-ML
Avg. Wet Density STD (lb/ft^3)	***5.3***	***10.1***(6.5)	***0.6***	***0.9***	***1.9***	***4.0***
Avg. Vol. Moisture STD (%)	***1.4***	***2.3***(1.5)	***0.2***	***0.5***	***0.4***	***1.0***
Avg. Dry Density STD (lb/ft^3)	***3.9***	***7.8***(5.0)	***0.4***	***0.5***	***1.5***	***3.0***
Avg. Percent Moisture STD (%)	***1.0***	***1.3***(0.9)	***0.1***	***0.3***	***0.3***	***0.7***

Table 3-13. Summary of Six Soil Types and Average Standard Deviations (Density and Moisture)

4.0 Controlled Field Test ASTM Test 3

Four operators, each with a same SDG unit, took four sets of measurements at a single location, thus sixteen measurement sets were completed with each unit. For each measurement set, the standard clover-leaf pattern of five was used. This test was designed to show the density and moisture spread of a single instrument with four operators on several soil types.

Tables 4-1 and 4-2 display the data and standard deviations of the SDG data on the **4" Gravel Borrow** material. Table 4-1 is the wet density, volumetric moisture, dry density and percent moisture of the sixteen measurements completed with both instrument at different locations. Table 4-2 is the standard deviations of the two instruments and the computed average standard deviations for the wet density, volumetric moisture, dry density and percent moisture. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 3.1 lb/ft^3, 0.8%, 2.3 lb/ft^3 and 0.5%, respectively.

Location: Icon Materials, Auburn, Washington
Material: 4" Gravel Borrow (USCS: SP)

	Operator	Location X (SN 4)				Location Y (SN 16)			
	Test	A	B	C	D	A	B	C	D
Wet Density (lb/ft^3)	1	131	131	132.6	133.9	135	138.6	137.7	140.6
	2	129.6	132.8	139	127.8	130.1	139.3	137.9	143.5
	3	133.9	131.5	133.6	136.4	135.8	137.2	140.9	143.7
	4	133.9	133	134.3	130.7	137.8	138.2	141	142.8
Vol. Moist (%)	1	8.5	8.5	8.9	9.1	9.8	10.6	10.4	11.1
	2	8	8.9	10.7	7.7	8.5	10.8	10.5	11.8
	3	9.2	8.6	9.1	10	10	10.3	11.2	11.8
	4	9.2	8.9	9.2	8.4	10.4	10.5	11.2	11.6
Dry Density (lb/ft^3)	1	122.5	122.6	123.8	124.7	125.2	128	127.3	129.5
	2	121.6	123.9	128.3	120	121.6	128.5	127.4	131.6
	3	124.7	122.9	124.5	126.5	125.8	126.9	129.7	131.9
	4	124.8	124.1	125	122.3	127.3	127.7	129.8	131.2
Percent Moist (%)	1	6.9	6.9	7.2	7.3	7.8	8.2	8.2	8.6
	2	6.6	7.2	8.3	6.4	7	8.4	8.2	9
	3	7.3	7	7.3	7.9	7.9	8.1	8.6	9
	4	7.4	7.2	7.4	6.9	8.2	8.3	8.6	8.9

Table 4-1. SDG Data on 4" Gravel Borrow (USCS: SP)

	Location X (SN 4)	Location Y (SN 16)	Average
Standard Deviation Wet Density (lb/ft^3)	2.7	3.5	3.1
Standard Deviation Vol. Moist (%)	0.7	0.8	0.8
Standard Deviation Dry Density (lb/ft^3)	2.0	2.6	2.3
Standard Deviation Percent Moist (%)	0.5	0.5	0.5

Table 4-2. Standard Deviation Summary of SDG on 4" Gravel Borrow (USCS: SP)

Tables4- 3 and 4-4 display the data and standard deviations of the SDG data on the **1 ¼" Crushed Base Course** material. Table 4-3 is the wet density, volumetric moisture, dry density and percent moisture of the sixteen measurements completed with both instrument at different locations. Table 4-4 is the standard deviations of the two instruments and the computed average standard deviations for the wet density, volumetric moisture, dry density and percent moisture. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 2.8 lb/ft^3, 0.6%, 2.2 lb/ft^3 and 0.3%, respectively.

Location: Icon Materials, Auburn, Washington
Material: 1 ¼" Crushed Base Course (USCS: GP-GM)

	Operator	Location X (SN 4)				Location Y (SN 16)			
	Test	A	B	C	D	A	B	C	D
Wet Density (lb/ft^3)	1	128.6	127.8	134.6	129.0	140.4	139.3	146.1	148.0
	2	128.8	130.2	131.2	129.3	138.6	142.0	147.3	148.4
	3	128.6	128.4	128.3	128.5	138.1	145.0	147.7	148.1
	4	129.6	131.2	131.2	127.8	141.8	145.7	147.3	148.6
Vol. Moist (%)	1	8.1	8.0	9.6	8.2	10.8	10.6	12.1	12.5
	2	8.2	8.5	8.7	8.3	10.4	11.2	12.3	12.6
	3	8.1	8.0	8.1	8.1	10.3	11.9	12.4	12.5
	4	8.4	8.7	8.7	7.9	11.1	12.0	12.3	12.6
Dry Density (lb/ft^3)	1	120.5	119.8	125.1	120.7	129.6	128.7	134.1	135.6
	2	120.6	121.7	122.5	121.0	128.2	130.8	134.9	135.8
	3	120.5	120.4	120.2	120.4	127.8	133.2	135.3	135.6
	4	121.3	122.5	122.6	119.9	130.7	133.7	135.0	136.0
Percent Moist (%)	1	6.8	6.7	7.6	6.8	8.3	8.2	9.0	9.2
	2	6.8	7.0	7.1	6.8	8.2	8.6	9.1	9.2
	3	6.8	6.7	6.7	6.7	8.1	8.9	9.2	9.2
	4	6.9	7.1	7.1	6.6	8.5	9.0	9.1	9.3

Table 4-3. SDG Data on 1 ¼" Crushed Base Course (USCS: GP-GM)

	Location X (SN 4)	Location Y (SN 16)	Average
Standard Deviation Wet Density (lb/ft^3)	1.8	3.8	2.8
Standard Deviation Vol. Moist (%)	0.4	0.8	0.6
Standard Deviation Dry Density (lb/ft^3)	1.4	3.0	2.2
Standard Deviation Percent Moist (%)	0.3	0.4	0.3

Table 4-4. Standard Deviation Summary of SDG on 1 ¼" Crushed Base Course (USCS: GP-GM)

Tables 4-5 and 4-6 display the data and standard deviations of the SDG data on the **Red Silt Clay** material. Table 4-5 is the wet density, volumetric moisture, dry density and percent moisture of the sixteen measurements completed with both instrument at different locations. Table 4-6 is the standard deviations of the two instruments and the computed average standard deviations for the wet density, volumetric moisture, dry density and percent moisture. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 0.5 lb/ft^3, 0.1%, 0.4 lb/ft^3 and 0.1%, respectively.

Location: Qore, Jefferson, Georgia
Material: Red Silt Clay (USCS: CL)

	Operator / Test	Location X (SN 5)				Location Y (SN 8)			
		A	B	C	D	A	B	C	D
Wet Density (lb/ft^3)	1	129.0	127.7	129.2	129.2	127.0	127.9	128.5	128.2
	2	128.7	129.0	130.6	129.4	127.5	128.0	127.7	127.9
	3	128.8	128.9	129.2	129.4	127.1	128.2	127.8	128.0
	4	129.1	128.8	128.4	129.6	127.5	127.9	127.8	127.7
Vol. Moist (%)	1	23.6	23.3	23.7	23.7	23.2	23.5	23.7	23.5
	2	23.6	23.7	24.2	23.7	23.4	23.5	23.4	23.5
	3	23.6	23.6	23.7	23.7	23.3	23.5	23.4	23.5
	4	23.7	23.6	23.5	23.8	23.4	23.5	23.4	23.4
Dry Density (lb/ft^3)	1	105.3	104.4	105.5	105.5	103.8	104.4	104.8	104.6
	2	105.1	105.4	106.5	105.6	104.1	104.5	104.3	104.5
	3	105.2	105.3	105.5	105.7	103.9	104.6	104.4	104.5
	4	105.4	105.2	105.0	105.8	104.2	104.5	104.4	104.3
Percent Moist (%)	1	22.4	22.3	22.5	22.5	22.4	22.5	22.6	22.5
	2	22.4	22.4	22.7	22.5	22.4	22.5	22.4	22.5
	3	22.4	22.4	22.5	22.5	22.4	22.5	22.5	22.5
	4	22.5	22.4	22.3	22.5	22.4	22.5	22.5	22.4

Table 4-5. SDG Data on Red Silt Clay (USCS: CL)

	Location X (SN 5)	Location Y (SN 8)	Average
Standard Deviation Wet Density (lb/ft^3)	0.6	0.4	0.5
Standard Deviation Vol. Moist (%)	0.2	0.1	0.1
Standard Deviation Dry Density (lb/ft^3)	0.4	0.3	0.4
Standard Deviation Percent Moist (%)	0.1	0.05	0.1

Table 4-6. Standard Deviation Summary of SDG on Red Silt Clay (USCS: CL)

Tables 4-7 and 4-8 display the data and standard deviations of the SDG data on the Georgia **Graded Aggregate Base** material. Table 4-7 is the wet density, volumetric moisture, dry density and percent moisture of the sixteen measurements completed with both instrument at different locations. Table 4-8 is the standard deviations of the two instruments and the computed average standard deviations for the wet density, volumetric moisture, dry density and percent moisture. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 0.7 lb/ft^3, 0.3%, 0.4 lb/ft^3 and 0.2%, respectively.

Location: Qore, Jefferson, Georgia
Material: Graded Aggregate Base (USCS: GP-GM)

	Operator Test	Location X (SN 5) A	B	C	D	Location Y (SN 8) A	B	C	D
Wet Density (lb/ft^3)	1	136.4	137.7	139.2	139.5	140.9	141.9	142.2	141.8
	2	138.2	138.4	139.2	139.4	141.5	141.6	142.4	141.5
	3	138.5	138.5	139.6	139.2	141.0	142.0	142.4	141.9
	4	138.9	138.6	139.8	139.0	140.1	141.6	142.4	142.2
Vol. Moist (%)	1	7.7	8.3	8.9	9.0	9.8	10.2	10.3	10.2
	2	8.5	8.5	8.9	9.0	10.0	10.1	10.4	10.0
	3	8.6	8.6	9.0	8.9	9.8	10.2	10.4	10.2
	4	8.8	8.6	9.1	8.8	9.4	10.1	10.4	10.3
Dry Density (lb/ft^3)	1	128.7	129.5	130.4	130.5	131.1	131.7	131.8	131.7
	2	129.8	129.8	130.3	130.4	131.5	131.5	132.0	131.5
	3	129.9	129.9	130.5	130.3	131.2	131.7	132.0	131.7
	4	130.2	130.0	130.7	130.2	130.7	131.5	132.0	131.8
Percent Moist (%)	1	6.0	6.4	6.8	6.9	7.4	7.7	7.8	7.7
	2	6.5	6.6	6.8	6.9	7.6	7.7	7.9	7.6
	3	6.6	6.6	6.9	6.8	7.5	7.8	7.9	7.7
	4	6.7	6.6	7.0	6.8	7.2	7.7	7.9	7.8

Table 4-7. SDG Data on Graded Aggregate Base (USCS: GP-GM)

	Location X (SN 5)	Location Y (SN 8)	Average
Standard Deviation Wet Density (lb/ft^3)	0.8	0.6	0.7
Standard Deviation Vol. Moist (%)	0.4	0.3	0.3
Standard Deviation Dry Density (lb/ft^3)	0.5	0.4	0.4
Standard Deviation Percent Moist (%)	0.3	0.2	0.2

Table 4-8. Standard Deviation Summary of SDG Graded Aggregate Base (USCS: GP-GM)

Tables 4-9 and 4-10 display the data and standard deviations of the SDG data on the Texas **Red Sand with Rock** material. Table 4-9 is the wet density, volumetric moisture, dry density and percent moisture of the sixteen measurements completed with both instrument at different locations. Table 4-10 is the standard deviations of the two instruments and the computed average standard deviations for the wet density, volumetric moisture, dry density and percent moisture. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 4.4 lb/ft^3, 1.0%, 3.5 lb/ft^3 and 0.6%, respectively.

Location: Clough Harbour, Oklahoma/Texas
Material: Red Sand with Rock (USCS: GW-GM)

	Operator / Test	Location X (SN 5) A	Location X (SN 5) B	Location X (SN 5) C	Location X (SN 5) D	Location Y (SN 3) A	Location Y (SN 3) B	Location Y (SN 3) C	Location Y (SN 3) D
Wet Density (lb/ft^3)	1	114.9	118.6	128.3	127.4	121.5	126.4	120.2	128.0
	2	115.3	121.8	127.2	128.5	121.9	127.0	119.2	129.5
	3	119.7	124.1	129.2	124.5	120.9	127.6	124.5	131.1
	4	120.6	126.1	130.2	123.8	120.6	128.5	124.3	131.1
Vol. Moist (%)	1	5.1	5.9	8.0	7.8	6.3	7.4	6.1	7.8
	2	5.2	6.6	7.7	8.0	6.4	7.5	5.9	8.1
	3	6.1	7.1	8.1	7.1	6.2	7.7	7.0	8.4
	4	6.3	7.5	8.4	7.0	6.2	7.9	7.0	8.4
Dry Density (lb/ft^3)	1	109.8	112.7	120.3	119.6	115.1	119.0	114.1	120.2
	2	110.2	115.2	119.5	120.5	115.5	119.5	113.3	121.4
	3	113.6	117.0	121.1	117.3	114.7	120.0	117.5	122.6
	4	114.3	118.6	121.8	116.8	114.5	120.6	117.3	122.7
Percent Moist (%)	1	4.6	5.2	6.6	6.5	5.5	6.2	5.3	6.5
	2	4.7	5.7	6.5	6.6	5.6	6.3	5.2	6.7
	3	5.4	6.0	6.7	6.1	5.4	6.4	6.0	6.9
	4	5.5	6.3	6.9	6.0	5.4	6.5	5.9	6.9

Table 4-9. SDG Data on Red Sand with Rock (USCS: GW-GM)

	Location X (SN 5)	Location Y (SN 3)	Average
Standard Deviation Wet Density (lb/ft^3)	4.8	4.0	4.4
Standard Deviation Vol. Moist (%)	1.0	0.9	1.0
Standard Deviation Dry Density (lb/ft^3)	3.8	3.2	3.5
Standard Deviation Percent Moist (%)	0.7	0.6	0.6

Table 4-10. Standard Deviation Summary of Red Sand with Rock (USCS: GW-GM)

Tables 4-11 and 4-12 display the data and standard deviations of the SDG data on the Texas **Red Sandy Clay** material. Table 4-11 is the wet density, volumetric moisture, dry density and percent moisture of the sixteen measurements completed with both instrument at different locations. Table 4-12 is the standard deviations of the two instruments and the computed average standard deviations for the wet density, volumetric moisture, dry density and percent moisture. The average wet density, volumetric moisture, dry density and percent moisture standard deviations are 3.5 lb/ft^3, 0.9%, 2.6 lb/ft^3 and 0.6%, respectively.

Location: Clough Harbour, Oklahoma/Texas
Material: Red Sandy Clay (USCS: CL-ML)

	Operator Test	Location X (SN 5)				Location Y (SN 3)			
		A	B	C	D	A	B	C	D
Wet Density (lb/ft^3)	1	117.7	114.4	115.4	118.4	120.4	108.6	110.4	110.3
	2	119.7	115.6	112.8	118.5	118.7	112.6	108.5	109.1
	3	119.5	115.4	117.9	118.6	117.9	109.0	110.3	108.9
	4	119.8	115.9	123.0	119.4	118.9	108.9	110.1	106.3
Vol. Moist (%)	1	11.8	11.1	11.3	12.0	12.1	9.0	9.6	9.4
	2	12.3	11.4	10.6	12.0	11.7	10.2	9.2	9.1
	3	12.2	11.3	11.9	12.0	11.5	9.0	9.3	9.0
	4	12.3	11.5	13.3	12.2	11.7	9.0	9.3	8.4
Dry Density (lb/ft^3)	1	105.9	103.3	104.0	106.4	108.3	99.6	100.8	100.9
	2	107.4	104.2	102.2	106.5	107.1	102.4	99.2	100.0
	3	107.3	104.1	106.0	106.5	106.4	100.0	101.0	99.9
	4	107.5	104.4	109.7	107.2	107.2	99.9	100.8	98.0
Percent Moist (%)	1	11.2	10.7	10.9	11.3	11.2	9.0	9.5	9.3
	2	11.4	10.9	10.4	11.3	10.9	10.0	9.3	9.1
	3	11.4	10.9	11.2	11.3	10.8	9.0	9.2	9.0
	4	11.4	11.0	12.1	11.4	10.9	9.0	9.3	8.6

Table 4-11. SDG Data on Red Sandy Clay (USCS: CL-ML)

	Location X (SN 5)	Location Y (SN 3)	Average
Standard Deviation Wet Density (lb/ft^3)	2.5	4.5	3.5
Standard Deviation Vol. Moist (%)	0.6	1.2	0.9
Standard Deviation Dry Density (lb/ft^3)	1.9	3.3	2.6
Standard Deviation Percent Moist (%)	0.4	0.8	0.6

Table 4-12. Standard Deviation Summary of Red Sandy Clay (USCS: CL-ML)

Summarized in Table 4-13, ASTM Test 3, for each of the six soil types measured upon, the average wet density standard deviation with one instrument, four operators (each operator took four measurements), was less than or equal to 3.5 lb/ft^3. The average volumetric moisture content standard deviation with one instrument and four operators was less than or equal to 1.0%. The average dry density standard deviation with one instrument and four operators was less than or equal to 2.6 lb/ft^3. The average percent moisture standard deviation with one instrument and four operators was less than or equal to 0.6%.

Location: All
Material: All

USCS:	SP	GP-GM	CL	GP-GM	GW-GM	CL-ML
Avg. Wet Density STD (lb/ft^3)	3.1	2.8	0.5	0.7	4.4	3.5
Avg. Vol. Moisture STD (%)	0.8	0.6	0.1	0.3	1.0	0.9
Avg. Dry Density STD (lb/ft^3)	2.3	2.2	0.4	0.4	3.5	2.6
Avg. Percent Moisture STD (%)	0.5	0.3	0.1	0.2	0.6	0.6

Table 4-13. Summary of Six Soil Types and Average Standard Deviations (Density and Moisture)

5.0 Controlled Field Test ASTM Test Summary

Test 1: Four operators, each with a different SDG unit, took four sets of five measurements, each at a different location, only picking up in-between each of the twenty measurements and placing it back in the same spot. This test was designed to show the usual density and moisture spread of a measurement using several instruments, operators and test locations for multiple soil types.

Summarized in Table 5-1, ASTM Test 1, for each of the six soil types measured upon, the average wet density standard deviation was less than 2.0 lb/ft^3, the average volumetric moisture content standard deviation was less than 0.5%, the average dry density standard deviation was less than 1.5 lb/ft^3 and the average percent moisture content standard deviation was 0.3% or less.

Test 2: Four operators, each with a different SDG unit, took two sets of measurements at six locations. For each measurement set, the standard clover-leaf pattern of five was used. This test was designed to show the density and moisture spread of four instruments with four operators on several soil types.

Summarized in Table 5-2, ASTM Test 2, for each of the six soil types measured upon, the average wet density standard deviation with four instruments and four operators was less than or equal to 6.5 lb/ft^3. The average volumetric moisture content standard deviation with four instruments and four operators was less than or equal to 1.5%. The average dry density standard deviation with four instruments and four operators was less than or equal to 5.0 lb/ft^3. The average percent moisture standard deviation with four instruments and four operators was less than or equal to 1.0%.

Test 3: Four operators, each with a same SDG unit, took four sets of measurements at a single location, thus sixteen measurement sets were completed with each unit. For each measurement set, the standard clover-leaf pattern of five was used. This test was designed to show the density and moisture spread of a single instrument with four operators on several soil types.

Summarized in Table 5-3, ASTM Test 3, for each of the six soil types measured upon, the average wet density standard deviation with one instrument, four operators (each operator took four measurements), was less than or equal to 3.5 lb/ft^3. The average volumetric moisture content standard deviation with one instrument and four operators was less than or equal to 1.0%. The average dry density standard deviation with one instrument and four operators was less than or equal to 2.6 lb/ft^3. The average percent moisture standard deviation with one instrument and four operators was less than or equal to 0.6%.

Materials Tested:

	USCS	Common Name
1	***SP*** (Poorly graded sand with gravel)	4” Gravel Borrow
2	***GP-GM*** (Poorly graded gravel with silt & sand)	1 ¼” Crushed Base Course
3	***CL*** (Lean clay)	Red Silt Clay
4	***GP-GM*** (Poorly graded gravel with silt & sand)	Graded Aggregate Base
5	***GW-GM*** (Well graded gravel with silt & sand)	Red Sand with Rock
6	***CL-ML*** (Silty clay)	Red Sandy Clay

USCS:	**SP**	**GP-GM (w/o SN 8)**	**CL**	**GP-GM**	**GW-GM**	**CL-ML**
Wet Density STD (lb/ft^3)	1.931	1.667 (1.060)	0.288	0.750	1.323	0.985
Vol. Moist STD (%)	0.485	0.354 (0.214)	0.080	0.319	0.301	0.219
Dry Density STD (lb/ft^3)	1.447	1.313 (0.846)	0.208	0.431	1.022	0.766
Percent Moist STD (%)	0.316	0.174 (0.115)	0.033	0.222	0.225	0.123

Table 5-1. ASTM Test 1 Summary (1 instrument with 1 operator, each at 1 location)

USCS:	**SP**	**GP-GM (w/o SN 8)**	**CL**	**GP-GM**	**GW-GM**	**CL-ML**
Avg. Wet Density STD (lb/ft^3)	*5.3*	*10.1* (6.5)	*0.6*	*0.9*	*1.9*	*4.0*
Avg. Vol. Moisture STD (%)	*1.4*	*2.3* (1.5)	*0.2*	*0.5*	*0.4*	*1.0*
Avg. Dry Density STD (lb/ft^3)	*3.9*	*7.8* (5.0)	*0.4*	*0.5*	*1.5*	*3.0*
Avg. Percent Moisture STD (%)	*1.0*	*1.3* (0.9)	*0.1*	*0.3*	*0.3*	*0.7*

Table 5-2. ASTM Test 2 Summary – (4 instruments with 4 operators at 6 locations)

USCS:	SP	GP-GM	CL	GP-GM	GW-GM	CL-ML
Avg. Wet Density STD (lb/ft^3)	3.1	2.8	0.5	0.7	4.4	3.5
Avg. Vol. Moisture STD (%)	0.8	0.6	0.1	0.3	1.0	0.9
Avg. Dry Density STD (lb/ft^3)	2.3	2.2	0.4	0.4	3.5	2.6
Avg. Percent Moisture STD (%)	0.5	0.3	0.1	0.2	0.6	0.6

Table 5-3. ASTM Test 3 Summary – (1 instrument with 4 operators at 1 location)

APPENDIX F

SDG Draft ASTM Standard

Appendix F. SDG Draft ASTM Standard

Standard Test Method for
In-Place Determination of Density and Water Content of Soil By Electrical Impedance Spectroscopy[1]

This standard is issued under the fixed designation X XXXX; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the procedures for determining the in-place relative compaction, density and gravimetric water content of unbound soil and soil aggregate mixtures by measuring changes in the electromagnetic properties resulting from the compaction process.

1.2 The total or wet density and moisture of soil and soil-aggregate is measured by an electrical impedance spectroscopy device. The spectral analysis of the return signal is used to determine the total or wet density and moisture is based on the sensor design and hardware when the device is operated in contact with or in proximity to the soil surface.

1.3 SI Units – The values stated in SI units are to be regarded as the standard. The value stated in inch-pound units (ft-lb units) are provided for information only.

1.4 All observed and calculated values shall conform to the Guide for Significant Digits and Rounding established in Practice D6026.

1.4.1 The procedures used to specify how data is collected, recorded, and calculated in this standard are regarded as the industry standard. In addition, they are representative of the significant digits that should generally be retained. The procedures used do not consider material variation, purpose for obtaining the data, special purpose studies, or any considerations for the users objectives; and it is common practice to increase or decrease the number of significant digits of reported data commensurate with these considerations. It is beyond the scope of this standard to consider significant digits used in the analysis methods for engineering design.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:* [2]

---

[1] This test method is under the jurisdiction of ASTM Committee *D18 Soil and Rock* and is the direct responsibility of Subcommittee *D18.08 on Special and Construction Control Tests*

.

Current edition approved XXX. XX, XXXX. Published XX XXXX.

[2] For Referenced ASTM Standards, visit the ASM|TM Website at www.astm.org, or contact ASTM Customer Service at service@astm.org. for Annual Book of ASTM Standards volume information, refer to the standard's Document Summary Page on the ASTM Website.

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D698 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3, 600 kN-m/m^3)

D1556 Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method

D1557 Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (56,000 ft-lbf/ft^3, 2,700 kN-m/m^3)

D2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber Balloon Method

D2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soils and Rock by Mass

D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)

D2488 Practice for Description and Identification of Soils (Visual-Manual Method)

D2937 Test Method for Density of Soil and Rock by the Drive-Cylinder Method

D3740 Practice for Minimum requirements for Agencies Engaged in the Testing and/or Inspection of Soil and Rock as Used in Engineering Design and Construction

D4253 Test Methods for the Maximum Index Density and Unit Weight of Soils Using a Vibratory Table

D4254 Test Methods for the Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density

D4494 Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

D4643 Test Method for Determination of Water (Moisture) Content of Soil by Microwave Oven Method

D4718 Practice for the Correction of Unit Weight and Water Content for Soils Containing Oversize Particles

D4959 Test Method for Determination of Water (Moisture) Content of Soil by Direct Heating Method

D6026 Practice for Using Significant Digits in Geotechnical Data

D6780-05 Standard Test Method for Water Content and Density of Soil in Place by Time Domain Reflectometry (TDR)

D6938-07b Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

3. Terminology

3.1 *Definitions:* See Terminology D653 for General Definitions

4. Significance and Use

4.1 The Test Method Described is useful as a rapid, non-destructive technique for determining the in-place density total density and water content of soil and soil-aggregate mixtures and the determination of Dry Density.[3]

4.2 This Method is used for Quality Control and acceptance of compacted soil and soil-aggregate mixtures as used in construction and also for research and development. The non-destructive nature allows for repetitive measurements at a single test location and statistical analysis of the results.

4.3 Density – The density determined by the electrical impedance spectroscopy measurement represents the average value in the measuring volume of the instrument.

4.4 Water Content – The water content determined by the electrical impedance spectroscopy measurement represents the average value in the measuring volume of the instrument.

5. Interferences

5.1 Measurements may be affected by chemical and mineralogical composition of the material being tested.

5.2 Measurements may be affected by non-homogeneous soils and surface texture (see 10.2)

5.3 Measurements are influenced more by the density and water content of the material near the surface.

5.4 Oversized particles in the measurement volume may cause higher or lower density results. Where lack of uniformity in the soil is suspected, due to layering, aggregates, or voids, the test site should be excavated and visually examined to determine if the material is representative of the in-situ material in general and if an oversize correction is required in accordance with Practice D 4718.

5.5 The measured Volume is approximately $0.0051m^3$ ($0.18\ ft^3$). The Actual measured volume is indeterminate and varies with the apparatus and the density of the material[4].

6. Apparatus

6.1 *Electronic Sensing Device* – While the exact details of construction of the apparatus may vary, the device shall meet the outline below:

6.1.1 An electronic measuring device, capable of being seated on or above the surface of the material under test.

6.1.2 The device shall be housed in an enclosure of heavy-duty construction and designed for taking in-situ density and water content measurements of soil and soil-aggregate mixtures.

---

[3] The quality of the result produced by this standard test method is dependent on the competence of the personnel performing it, and the suitability of the equipment and facilities used. Agencies that meet the requirements of Practice D 3740 are generally considered capable of competent and objective Sampling / Testing / Inspection, and the like. Users of this standard are cautioned that compliance with Practice D 3740 does not in itself assure reliable results. Reliable results depend on many factors; Practice D 3740 provides a means of evaluation some of those factors.

[4] The volume of field compacted material represented by a test can effectively be increased by repeating the test at adjacent locations and averaging the results.

6.1.3 The device shall function at the normal temperatures and environmental conditions experienced during earthwork operations.

6.1.4 The device shall include the internal circuitry suitable for displaying individual measurements to allow operators to record the readings.

6.1.5 The device shall employ suitable electronic circuitry to provide power and signal conditioning to the sensor to provide the data acquisition and readout function; and, allow calibration of the unit over the expected range of application conditions and materials.

6.2 Surface Preparation Plate – A rigid plate of suitable size and material, that may be used to flatten and prepare the testing surface before density and water content measurements are made.

6.3 Standard Reference Block – a block of material used for checking device operation and to establish conditions before actual measurements are made.

7. Calibration and Standardization

7.1 Calibration of the device shall be performed by the device manufacturer or a certified repair and calibration facility.

7.2 Standardization:

7.2.1 The standardization for this device is performed on a reference block provided by the manufacturer. The standardization procedure verifies the operability of the device.

7.2.2 Standardization of the gauge shall be performed and recorded as required by Local / State / Federal requirements, or as recommended by the manufacturer.

7.2.3 Standardization shall be in accordance with the procedure recommended by the device manufacturer to establish the compliance with the standard measurement to the accepted range.

7.2.4 If for any reason the measured density or moisture content becomes suspect during the day's use, perform another standardization check to verify the operability of the device.

8. Procedure

8.1 Preparation of test site:

8.1.1 Select a test location in accordance with the contract documents, located to be representative of the total material being placed and minimize potential interferences.

8.1.2 Remove all loose and disturbed material and additional material to as necessary to expose the true surface of the material to be tested.

8.1.3 Prepare a horizontal area of sufficient size to accommodate the device by scraping or grading the surface to a smooth condition as recommended by the manufacturer.

8.2 Power the device on sufficiently in advance of performing measurements to allow the device to stabilize as recommended by the manufacturer.

8.3 Place the device on the surface of the material to be tested.

8.4 If the device is so equipped set the depth of test.

8.5 Secure and record one or more density and water content measurements.

9. Calculation or Interpretation of Results

9.1 Wet Density:

9.1.1 Read and Record the density value to the nearest 1 kg/m^3 (0.1 lbm/ft^3).

9.2 Dry Density:

9.3 Read and Record the density value to the nearest 1 kg/m^3 (0.1 lbm/ft^3).

9.4 Water Content:

9.4.1 Read and Record water content to the nearest 0.1 %.

9.5 Determine Percent Compaction:

9.5.1 It may be desired to express the in-place dry density as a percentage of a laboratory density such as Test Methods D698, D1557, D4253, or D4254. This relationship can be calculated by dividing the In-Place Dry Density by the Laboratory Maximum Dry Density and multiplying by 100. Procedures for calculating relative density are provided in Test Method D4254 which requires that Test Method D4253 also be performed. Corrections for oversize material, if required, shall be performed in accordance with Practice D4718.

10. Report

10.1 The Test Report shall include the following:

10.1.1 Make, Model and Serial Number of the device.

10.1.2 Operators name.

10.1.3 Date of last calibration or calibration verification (or on file with the testing agency).

10.1.4 Test Site Identification.

10.1.5 Visual description of the material being tested.

10.1.6 Dry Density in kg/m^3 or lbm/ft^3.

10.1.7 Wet density in kg/m^3 or lbm/ft^3.

10.1.8 Water Content in percent

10.1.9 Any Correction to the report values and the reason for these changes (i.e. oversized particles, water content).

11. Precision and Bias

11.1 Precision:

11.1.1 Complete test data on precision in accordance E691 is not presented due to the nature of this test method. It is either not feasible or too costly at this time to have ten or more agencies participate in an in-situ testing program at a given site. The Subcommittee (D18.08) is seeking any data from the users of this test method that might be used to make a limited statement on precision. Task group D18.08.03 is looking into an ASTM sponsored ILS to generate data on a variety of soils for a precision statement.

11.2 Bias:

11.3 There are no accepted reference values for these test methods, therefore, bias cannot be determined.

12. Keywords

12.1 Compaction Test; acceptance testing; construction control; quality control; field density; in-place density; wet density; dry density; electromagnetic impedance spectroscopy; electronic density gauge; non-nuclear test method; non-destructive measurement

ANNEX

(Mandatory Information)

A1. CALIBRATION AND VERIFICATION

A1.1 Calibration and Verification of Density:

A1.1.1

A1.2 Calibration and Verification of Water Content:

A1.2.1

APPENDIX G

SDG User Manual

Appendix G. SDG User Manual

Soil Density Gauge
Beta Unit

Operator’s Handbook
TransTech Systems, Inc.

Telephone: (518) 370-5558 or
Toll Free in the US : 1 (800)724-6306
FAX: (518)370-5538

E-mail: sales @transtechsys.com

TransTech Systems Inc.

1594 State Street
Schenectady, New York 12304

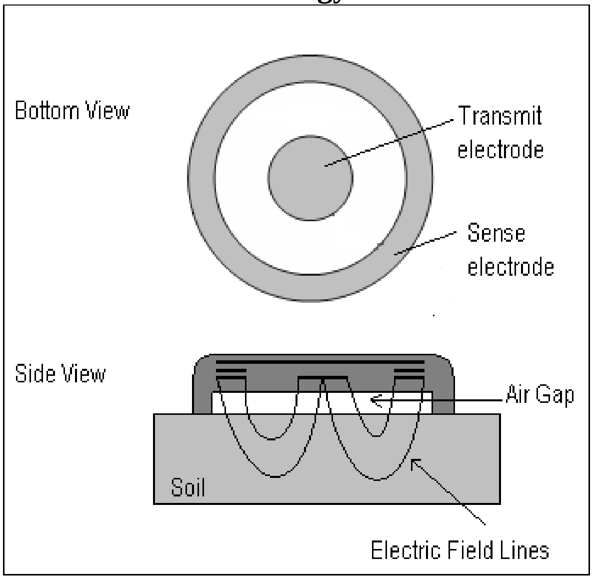
Table of Contents

Introduction

TransTech’s Soil Density Gauge (SDG) utilizes state of the art technology to get accurate soil density readings. It’s primary features are:

- No special license or radioactive materials required.
- Lightweight and easy to use.
- 12 hours of portable operation.
- Measures density in common units (pcf or kg/m^3).
- Measures percent moisture.
- Stores 30 readings on internal data logger.
- Data download via USB flash drive (comma delimited text file format).

Measurement Technology



Using electrical impedance spectroscopy (EIS) the SDG’s measurement permits separation of the effects of density and moisture content on the response of the soil to electromagnetic probing. The density, or compaction level, is measured by the response of the SDG’s electrical sensing field to changes in electrical impedance of the material matrix. Since the dielectric constant of air is much lower than that of the other soil constituents, as density/compaction increases, the combined dielectric constant increases because the percentage of air in the soil matrix decreases. The SDG performs a calculation on the measurement data that enables the device to report the soil’s density and moisture content.

Application Summary

The SDG is intended primarily for making density measurements on a standard 12 inch lift of soil during or after compaction. It is designed to measure coarse and fine grained materials common in standard soils used in civil construction projects. After configuring the gauge with soil properties from a standard particle size distribution report (ASTM D422) and Proctor test (ASTM D698 and D1557) the gauge will provide reliable and consistent measurements.

Safety

Every effort has been made to make the Soil Density Gauge convenient to use and inherently safe. The SDG uses no nuclear elements; it is based on safe, low-voltage direct current electrical measurement techniques. Like any instrument, however, the user should exercise care and common sense in its use to prevent mishaps.

Warning
Do not use the unit on or near electrical wiring.
A potential shock hazard exists if contact is made with the exposed wiring.

Warning
Use care in handling the unit. Personal injury can occur through improper handling.
Take proper care to avoid accidentally dropping the unit.

Caution
Turn the unit off when not in use and during transport.

Caution
Unauthorized disassembly of the unit will void the warranty.

Controls and Components

Contents

The SDG is packaged and shipped with the following components. Contact TransTech Systems Inc. Customer Service if any of the parts are missing.

- Storage/shipping case
- Operators handbook
- SDG Unit
- SDG handle
- 120/220V AC to 12V DC battery charger
- 12V DC Car Charger

External Components

Keypad

USB Port

Handle

Charger Connection

12V DC Charger

120/24V AC Charger

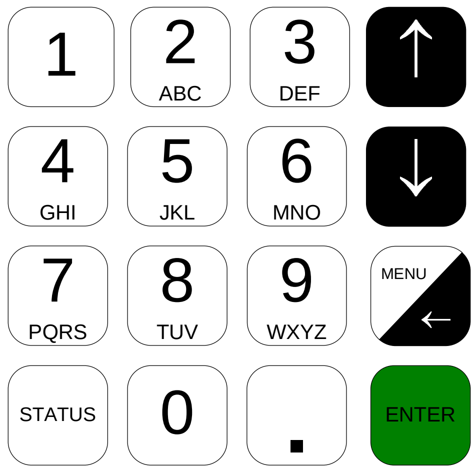
External Controls

External controls on the SDG consist of an ON/OFF switch and a sixteen key keypad for navigating through the user interface and entering alpha/numeric data.

The keypad on this beta unit is not laid out exactly as intended. Please refer to the following illustration when using the keypad to enter text on the SDG.

Note that the CAL key on the keypad is linked directly to the SDG Status Screen

Key pad on SDG



Reference illustration for alpha/numeric entry

Key	Function
0	For alpha/numeric entries the 0 will enter _, -, or 0
1-9	The number keys are used to select specific menu functions and to enter alpha/numeric text
↑ ↓	Arrow keys are used to scroll up and down on menu screens
ENTER	Executes a command or terminates an operation such as editing text
CAL	Links directly to the instrument Status Screen When in the Main Menu Adds a space when entering text.
Menu/←	Returns to the Main Menu or acts a backspace when entering data
“.”	Use as a decimal point

Prior to using the SDG for the first time the gauge will need to be configured to make measurements and record data correctly.

The following steps must be completed before operating the SDG:

1. Charge the Battery
2. Set the Local Time
3. Set the Date
4. Select Units of Measurement
5. Set up the GPS
6. Define the material being tested

Charge the Battery
Before the first use and after discharging the battery pack, a minimum of 5 hours should be allowed for charging.

To charge the unit, proceed as follows:

1) Turn the SDG unit OFF.
2) Connect the charger to the charger connector located on the side of the SDG.
3) Plug the charger into a standard AC outlet.
4) The red indicator lamp will turn off to indicate that the battery is charged.
5) Unplug the charger from the power source before disconnecting the charger from the SDG.

Battery voltage can be viewed on the Status Screen by pressing the CAL button on the keypad. A fully charged battery will display about 8 volts. The battery voltage will decrease as the SDG is used. A low battery warning will be displayed at about 7 volts. The gauge will continue to operate until the battery can not supply enough voltage to complete a measurement. **Depending on the condition of the batteries, once the voltage drops below 7 volts, the gauge may be able to take about 12 to 15 additional readings.** It is important to re-charge the battery after each use.

Set the Local Time

From the Main Menu select 3 to enter the Setup Menu. From the Setup Menu select 1 to set the date and time.

Main Menu

(1) Use Current Material
DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting

Setup Menu

(1) Date and Time
(2) Units
(3) GPS Setup
(4) Factory Settings

0 to Exit to Main Menu

The current time and date are displayed on the Date and Time Menu .To change the time select 1. Time is only displayed in the 24 hour format. The Set Time screen will display the new time as it is entered.

Date and Time Menu

(1) Set Time
13:20
(2) Set Date
03/10/08

0 Exit to Setup Menu

Set Time
Enter Time (24h)
HH:MM
XX:XX

UP) Exit to Date and Time Menu
ENTER to Accept New Time

Select ENTER to accept the new time.

Set the Date

From the Main Menu select 3 to enter the Setup Menu. From the Setup Menu select 1 to set the date and time.

Main Menu

(1) Use Current Material
DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting

Setup Menu

(1) Date and Time
(2) Units
(3) GPS Setup
(4) Factory Settings

0 to Exit to Main Menu

The current time and date are displayed on the Time and Date Menu .To change the date select 2. The date can be displayed in one of two formats, Month, Day, Year (MDY) or Day, Month, Year (DMY). On the Set Date screen select 1 to alternate between the two date formats.

Date and Time Menu

(1) Set Time
13:20
(2) Set Date
03/10/2008

0 Exit to Setup Menu

Set Date

(1) Date Format (MDY)
(2) Date 03/10/2008

0 Exit to Date and Time Menu

From the Set Date screen, select 2 to enter the new date.

Set Date

Enter Date

MM/DD/YY
XX/XX/XX

UP) Exit to Set Date Menu
ENTER to Accept New Date

Enter the new date and select ENTER to accept it.

Select Measurement Units

The SDG can measure density in either Pounds per Cubic Foot (pcf) or Kilograms per Cubic Meter (kg/m^3). The SDG also measures the surface temperature of the material being compacted using an infrared temperature sensor. The sensor can be configured to report temperature in degrees Fahrenheit or degrees Celsius. Note that the temperature displayed is not ambient temperature. At times the temperature of the material being compacted can vary greatly from the current air temperature.

To change units select 3 from the Main Menu to enter the Setup Menu. From the Setup Menu, select 2 to change the measurement units.

```
Main Menu

(1) Use Current Material
  DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting
```

```
Setup Menu

(1) Date and Time
(2) Units
(3) GPS Setup
(4) Factory Settings

0 to Exit to Main Menu
```

On the Units Screen, select 1 to alternate between pcf and kg/m^3 units of density. Select 2 to alternate between degrees Fahrenheit and degrees Celsius. The units displayed on the screen are the current units that the gauge is configured to display measurements in.

```
Select Units

(1) Density
    pcf
(2) Temperature
    Celcius

0 Exit to Set Up Menu
```

!! Note that changing between units of density will not change the value entered when defining a material. Errors in % Compaction reported at the end of a test are possible!!

Setup the GPS

The GPS on the SDG is configured to output Latitude and Longitude in the WGS 84 (World Geodetic System 1984) coordinate system. The GPS also outputs UTC (Coordinated Universal Time) based time and date. The SDG uses UTC in conjunction with GPS coordinates to validate the specific time and location that measurements are made. The user input Local Time is used and displayed for all other purposes. The SDG's GPS also outputs the number of satellites being tracked at a given time.

The GPS can be turned on or turned off depending on the measurement application. Turning off the GPS when not in use will extend the battery life and allow a greater number of tests between battery charges.

To view the GPS output or to turn the GPS on or off select 3 on the Main Menu to enter the Setup Menu. From the Setup Menu select 3 to view the GPS outputs, there will be a momentary pause after entering the GPS screen while the GPS receives satellite updates.

```
Main Menu

(1) Use Current Material
  DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting
```

```
Setup Menu

(1) Date and Time
(2) Units
(3) GPS Setup
(4) Factory Settings


0 to Exit to Main Menu
```

```
GPS Output

(1) Turn GPS Off
Latitude     42 47.1681N
Longitude  73 54.7786W
GPS Time    00:01:43
Date           04/24/08
Satellites    3

0 Exit to Set Up Menu
ENTER to Update
```

Current readings can be viewed on the GPS Output screen. Select 1 to turn the GPS On or Off. If the GPS is off, the command to turn the GPS on will be displayed as '(1) Turn GPS On'. When the GPS is off or not receiving satellite signals, no GPS information will be logged with density measurements in the data files. Selecting ENTER on the GPS screen will refresh the screen and update the data that is displayed.

Define or Edit a Material

The density determined by the SDG is highly material dependent so it is extremely important that the material properties from the Proctor Test and Gradation Report for the soil being tested are input accurately into the gauge.

The SDG is configured to store 12 unique materials that are identified by user selected descriptions. If 12 materials have been defined in the SDG and a 13th material is required, one of the original 12 will need to be modified to reflect the material properties of the new material. The properties of the new material will need to be input by editing the properties of a previously defined material. Once the old material properties are overwritten with new information, the old information is gone and the new information is saved in the gauge.

A new SDG will not have any defined materials stored in memory. The following sequence explains how to input material properties and how to edit previously input material definitions.

See Part 5 for explanations of the Material Properties.
See Part 6 for explanations of gradation and Proctor test reports.

Press 2 to view the Material Selection Menu.

Main Menu

(1) Use Current Material
DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting

Press 2 to Edit a User Defined Material

Material Selection Menu

(1) Select User Defined Material
(2) Edit User Defined Material

0 to Exit to Main Menu

A list of the first 6 of 12 available user defined materials will be shown. If twelve materials have not been defined, unused positions will be shown and named SOIL 2, SOIL3, etc… Use the up and down arrow keys to select the material you want to edit. As you scroll up and down the active soil will be highlighted.

Edit User Defined Material
DK BR SAND W GR
SOIL 2
SOIL 3
SOIL 4
SOIL 5
SOIL 6

UP/DOWN to Scroll
ENTER to Preview Material
0 to Exit to Main Menu

Highlight the material to be edited, and then press ENTER to view the first page of material properties. Press the Up or Down arrow key to view the second page of material properties.

Preview Material

Soil ID: 77.197
Description: DK BR SAND W GR
Max Dry Dens: 133.90
Opt Moisture:6.60
PL: 0.00
LL: 0.00
Cu: 7.57
Cc: 0.89
UP/DOWN to Scroll

Preview Material
%Gravel: 15.4
%Fines: 8.1
%Sand: 76.5
%Greater than 3 in.: 0.0
%Greater than ¾ in.: 7.3

UP/DOWN to Scroll
0 to Exit to Material Menu
ENTER to Edit Material

Confirm that the material displayed is the material to be edited then press ENTER. The Edit Material Screen will now be visible on the display. Use the arrow keys to scroll through the material properties and highlight the property to be edited. The active material property will be highlighted.

Edit Material 1 of 12

Description: DK BR SAND W GR
Soil ID: 77.197
MAX Dry Dens: 133.90
Opt Moisture: 6.60
PL: 0.00
LL: 0.00

UP/DOWN to Select Property
Press ENTER to Edit Property
0 to Exit to Main Menu

Edit Material 1 of 12

Soil ID: 77.197
MAX Dry Dens: 133.90
Opt Moisture: 6.60
PL: 0.00
LL: 0.00
Cu: 7.57

UP/DOWN to Select Property
Press ENTER to Edit Property
0 to Exit to Main Menu

Press ENTER to select the active material property and open an edit screen. The edit screen will display the current material property and display the new property as it is entered. Once the new property is correctly entered, press ENTER to accept the new property and return to the Edit Material screen which will reflect the change that was just made. Press the up arrow to return to the Edit Material Menu without making any changes.

Edit Material Property

ID: 77.197
New ID: 99.198

UP to Exit to Edit Material Menu
ENTER to Accept and Continue

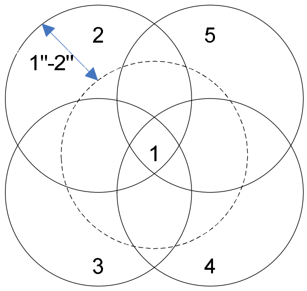
When all of the material properties displayed on the Edit Material screen are correct press 0 to return to the Main menu. The material that was just edited will now be the active material displayed on the Main Menu.

!! Note: The sum of %Greater the 3 inches, %Gravel, %Sand, and %Fines must add up to 100%. The default values programmed in the SDG software add up to 100%. As soon as one of those values is edited, the sum will no longer add up to 100% and an error message will be displayed until all of those gradation values are entered such that the sum is 100% again.!!

!! Note that Max Dry Density must be entered in the same units in which the gauge is configured to output results. If the gauge is configured to measure in pcf, input Max Dry Density in pcf !!

Part 2: Running a Test
After charging the battery, configuring the gauge, and defining a material to test, the SDG is ready to make density measurements.

Measurement Pattern
A complete test consists of five individual measurements taken in a "cloverleaf" pattern at the test location. Each of the five measurements takes about 15 seconds. The SDG is placed in position 1 for the first measurement and moved counterclockwise around position 1 as indicated in the illustration below. Upon completion of each reading, the SDG will prompt the operator to move to the next location.



Surface Preparation
While the SDG unit stands off from the soil, surface condition is still important. It is necessary for the soil surface to be free from any loose and disturbed material, stones, large air pockets or 'divots' and other debris. It is also important that the soil surface be flat. If it is not flat, flatten the surface or move the unit to a location where the surface is flatter. The SDG should not rock side-to-side when placed in a location to take a measurement; if it does, move to a new location or remove the obstacle that is causing the rocking being careful to not measure on top of any 'divot' left by removal of the object.

Large metal objects should not be within three feet of the gauge or underneath the soil while taking measurements. Measurements within ten feet of buried power lines should be avoided. When possible, measurements taken with an SDG near an edge or vertical obstruction should be taken at least three inches from that edge.

When placing the SDG at a location for a measurement, do not push down on the unit to 'seat' the unit in place. Set the unit down on the surface and check to see if it rocks side-to-side.

Do not touch the SDG while it is taking a measurement.

Measure Density

Turn the SDG on by pressing the ON button. After a few seconds the TransTech boot up screen will appear followed by the Main Menu screen.

TransTech Systems
Schenectady, NY, USA
Soil Density Gauge

Patents
5,900,736 6,414,497 7,219,024
Copyrighted 2008
SDG Model 1.2

Initializing...

The Main Menu screen will display five options as shown:

Main Menu

(1) Use Current Material
DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting

The Main Menu will display the currently selected material. If you wish to make a density measurement on that material, press the 1 key to display and verify its properties.

Preview Material

Soil ID: 77.197
Description: DK BR SAND W GR
Max Dry Dens: 133.90
Opt Moisture: 6.60
PL:
LL:
Cu: 7.57
Cd: 0.89
UP/DOWN to Scroll

Preview Material
%Gravel: 15.4
%Fines: 8.1
%Sand: 76.5
%Greater than 3 in.: 0.0
%Greater than ¾ in.: 7.3

UP/DOWN to Scroll
0 to Exit to Main Menu
ENTER to Accept Material

Use the arrow keys to view all of the user defined material properties.

Verify that the properties of the current material are correct for the material being measured and press ENTER to accept it and proceed to make a measurement.

Start Measurement

Current Material
DK BR SAND W GR

ENTER to Start Measurement
0 to Exit to Main Menu

After Pressing ENTER there will be a momentary delay while the GPS collects data.

Average Measurements
Soil type DK BR SAND W GR
1/30 Tests
Please move gauge to location 1

ENTER to Take Measurement
0 to Exit to Start Measurements

Location 1 of 5
Soil type DK BR SAND W GR

======================➔

Move the gauge to locations 2, 3, 4 and 5 and continue to take measurements. At the conclusion of a test the results are calculated and displayed as follows.

% Compaction: 107.0
% Moisture: 6.3
Wet Dens: 152.2 lb/ft^3
Dry Dens: 143.2 lb/ft^3
Vol. Moisture: 9.0 lb/ft^3
Latitude: 42 47.1681N
Longitude: 73 54.7786W
ENTER to Start Next Reading
0 to Exit to Main Menu

View and/or record the results and press ENTER to make another measurement on the same material or press 0 to return to the Main Menu.

Select a Different Material to Test

If the current material displayed on the Main Menu is different from the material being measured, a different material needs to be designated as the current material.

From the Main Menu, press 2 to enter the Material Selection Menu.

```
         Main Menu

(1) Use Current Material
  DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting
```

The option to select a different previously defined material or edit a previously defined material is available on the Material Selection Menu. Press 1 to select a different material.

```
   Material Selection Menu
(1) Select User Defined Material
(2) Edit User Defined Material



0 to Exit to Main Menu
```

On the User Defined Materials Screen, use the arrow keys to select the previously defined material to be measured. Press ENTER to preview the highlighted material.

Sect Material
DK BR SAND W GR
SOIL 2
SOIL 3
SOIL 4
SOIL 5
SOIL 6

UP/DOWN to Select Material
ENTER to Preview Material
0 to Exit to Main Menu

Preview Material

Soil ID: 77.197
Description: DK BR SAND W GR
Max Dry Dens: 133.90
Opt Moisture: 6.60
PL:
LL:
Cu: 7.57
Cc: 0.89
UP/DOWN to Scroll

Preview Material
%Gravel: 15.4
%Fines: 8.1
%Sand: 76.5
%Greater than 3 in.: 0.0
%Greater than ¾ in.: 7.3

UP/DOWN to Scroll
0 to Exit to Material Menu
ENTER to Accept Material

Preview the material and confirm the accuracy of the information displayed, then press ENTER to make this the current material. If the properties of the previewed material are not accurate press 0 to return to the User Defined Materials screen and either select a different material, or return to the Material Selection Screen to edit a previously defined material or define a new material.

Edit a User Defined Material
If one or more properties of a user defined material are incorrect, those properties can be edited or modified by selecting the Edit User Defined Material option on the Material Selection Menu. Follow the steps outlined on page 12 in the section entitled **Define or Edit a Material**.

Part 3: Data Storage and Downloading Data

The SDG saves two types of data files. One file contains information that is referred to as *diagnostic* data, the other file contains information that is referred to as *measurement* data. Data files can be removed from the SDG via a USB flash drive.

Measurement Data

The measurement data is an electronic record of all complete tests performed with the instrument (complete being the average of 5 individual measurements taken in a cloverleaf pattern). It is a comma delimited text file containing the following information:

> Test Number, Dry Density, Wet Density, Moisture Content, Volumetric Moisture, % Compaction, Material Name, Time, Date, Latitude, Longitude, UTC Time, UTC Date.

The measurement data is saved to a file that is automatically named by the SDG at the time of download. The following naming format is used:

month:month:day:day:hour:hour:minute:minute.mnt
03061510.mnt for March 6, 3:10 PM

Diagnostic Data

The diagnostic data contains all of the measurement data as well as information that indicates how the SDG is performing. This data is of little interest to gauge owners and operators but will be very helpful to TransTech in the event of an instrument malfunction. Similar to the measurement data, the diagnostic data is saved at the conclusion of a complete measurement. Data from partial measurements are not logged in memory.

The diagnostic data is saved to a file that is automatically named by the SDG at the time of download. The following naming format is used:

month:month:day:day:hour:hour:minute:minute.dat
03061510.dat for March 6, 3:10 PM

During the Beta test these files will be sent to TransTech on a regular basis.

Storage Capacity

The SDG is designed to store 30 complete tests (30 sets of five measurements). Upon completion of a set of five measurements, the average densities and moisture content as well as time, date and location information will automatically be written to a file and saved on the instrument. On occasions that operators do not complete the series of five tests that make up a measurement and either exit out of the measurement routine or turn off the instrument, that incomplete record will not be stored.

As the maximum storage capacity is approached (at 25 measurements) the SDG will issue a warning that the operator will need to download records from the data base. At this time it is advised that users download the data then clear the database. If the user continues to log 30 measurements, after the 30th measurement the SDG will alert them that no more data is being saved. The gauge will continue to operate as usual but will repeat the message before each measurement.

Downloading Data

From the Main Menu press 5 to enter the Data and Reports Menu

Main Menu

(1) Use Current Material
DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting

Data and Reports Menu

(1) Download Data to USB Drive
17/30 tests

(2) Clear Memory

0 to Exit to Main Menu

Press 1 to download the current diagnostic data

Download Menu

(1) Download Diagnostic Data
(2) Download Measurement Data

0 Exit to Data and Reports Menu

There will be a prompt to insert a USB flash drive and press enter to continue

```
Insert USB Flash Drive

ENTER to Download
0 to Exit to Data and Reports Menu
```

Press ENTER to initiate the download. An audible indication will be given upon completion of the download and the display will return to the Data and Reports Menu.

```
Downloading

04251115.dat

>    >    >    >    >
```

From the Data and Reports Menu, press 1 to enter the Download Menu and download measurement data if required, or press 2 to clear the memory.

Clearing the Data Base

Verify that the desired data files have been downloaded the proceed to clear the database. From the Main Menu press 5 to enter the Data and Reports Menu.

Main Menu

(1) Use Current Material
DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting

Data and Reports Menu

(1) Download Data to USB Drive
17/30 tests

(2) Clear Memory

0 to Exit to Main Menu

Press 2 to clear the data base.

Press ENTER on the Delete Data screen and the data base will be cleared.

Delete Data

!!!!!!
You Are About To Clear the Memory
!!!!!

0 Exit to Data and Reports Menu
ENTER to Clear Memory

Part 4: Instrument Status

Settings and Status of the SDG can be viewed by pressing the CAL button when viewing the Main Menu.

Status	
Date	03/17/08
Time	10:35
Battery	7.6
Data Storage	15/30
GPS Satellites	2
Temperature	22.88 C
Serial Number	000004
Software Version	1.4.3
0 To Update	ENTER To Return

The Status screen displays date, time, battery voltage, number of data records saved, status of the GPS, surface temperature of the material being tested, and the gauge's serial number. After viewing the gauge status, select ENTER to return to the Main Menu. The Status screen does not update automatically, press 0 to update the screen if necessary.

Time and Date
The time and date displayed on the status screen are the local time set by the user. The time displayed can be updated by pressing 0.

Battery
A fully charged battery will be operating at about 8 volts. At 7 volts a warning screen will indicate that the gauge should be recharged soon. The battery life remaining will vary with battery condition and gauge usage.

Data Storage
The SDG can store 30 readings in memory. The data storage indicator shows how many measurements are currently in storage. When the storage indicator reaches 25/30 the gauge will display a warning that the data base is almost full. Once the data base is full, the gauge will continue to operate but will not save any additional data until the data base is cleared.

GPS
The Status screen only indicates that the GPS is on or off. If the GPS is on it will display the number of satellites in range. If it is off, it will display OFF. Accessing the GPS functions form the Setup menu will display the current GPS outputs.

Temperature
The temperature displayed on the status screen is measured by an infrared sensor situated to measure the surface temperature of the material being tested. Note that this temperature is

not the ambient temperature and in some cases the material's surface temperature will be noticeably different from the ambient temperature.

Serial Number
The gauges six digit serial number is displayed here. This is entered at the factory before the gauge is shipped and cannot be edited by the user.

Software Version
The current version number of the software installed on the SDG is displayed here.

Part 5: Definitions and Calculations

Measurement Results
The following values are reported at the end of a measurement:

Wet Density is measured in Pounds per Cubic Foot (pcf) or Kilograms per Cubic Meter (kg/m^3) by the SDG

Volumetric Moisture is the mass of water per unit volume in pcf or kg/m^3, measured by the SDG.

% Moisture = water content in percent of dry density = $\dfrac{\text{Volumetric Moisture} \times 100}{\text{Wet Density} - \text{Volumetric Moisture}}$.

Dry Density = Wet Density – Volumetric Moisture in pcf or kg/m^3

% Compaction = $\dfrac{\text{Dry Density}}{\text{Max Dry Density}}$

Definitions of Material Properties
The following descriptions and material properties need to be entered in the gauge for measurement or data reporting purposes:

Description: Typically a brief description of the soil that allows the operator to visually identify the material being tested. Examples may include 'clayey sand red', or 'light brown silt'. Descriptions are limited to 16 characters.

Soil ID: A numeric entry that will associate the soil m=being tested with the gradation and proctor test report. Examples of soil ID's may include '33.1099' or '776632. Soil IDs are limited to 10 characters. **Do not enter letters or non numeric characters in the Soil ID.**

Max Dry Dens: This is the maximum dry density or target density or Proctor number for the material being tested. It is input in pcf or kg/m³. This value can be found in a Proctor test report completed in accordance with ASTM D 1557 or ASTM D 698. This is used by the SDG as the value against which the measured dry density is compared to calculate percent compaction.

Opt Moisture: This is the optimum moisture content for the material being tested. This value can be found in a compaction test report in completed accordance with ASTM D 1557 or ASTM D 698.

PL: Plastic Limit. This property describes soils with a high clay and silt content. It is defined as the moisture content in percent at which the sample begins to exhibit plastic behavior as it transitions from having semi-solid properties. This value is determined as outlined by ASTM D 4318.

LL: Liquid Limit. This property describes soils with a high clay and silt content. It is defined as the moisture content in percent at which a sample begins to exhibit liquid behavior as it transitions from having plastic properties. This value is determined as outlined by ASTM D 4318.

Cu: Coefficient of Uniformity. Cu is defined as the ratio of D_{60} / D_{10}, where D_{60} is the particle diameter of which 60% of the sample is smaller, and D_{10} is the particle diameter of which 10% of the sample is smaller. Cu can be calculated from values taken from a particle size distribution plot defined by ASTM D 422.

Cc: Coefficient of Curvature. Cc is defined as $D_{30}^2 / (D_{60} \times D_{10})$. Cc can be calculated from values taken from a particle size distribution plot defined by ASTM D 422.

% Gravel: The percentage of material by mass passing a 3 in. (75mm) sieve but retained on a #4 (4.75mm) sieve. %Gravel can be taken from a particle size distribution report defined by ASTM D 422.

% Sand: The percentage of material by mass passing a #4 (4.75mm) sieve but retained on a #200 (75μm). %Sand can be taken from a particle size distribution report defined by ASTM D 422.

% Fines: The percentage of material by mass passing a #200 (75μm) sieve. %Fines can be taken from a particle size distribution report defined by ASTM D 422.

% Greater than ¾ in: The percentage of material by mass retained on a ¾ inch (19.0mm) sieve. % Greater than ¾ inch can be taken from a particle size distribution report defined by ASTM D 422.

% Greater than 3 in: The percentage of material by mass retained on a 3 inch (75 mm) sieve. % Greater than 3 inches can be taken from a particle size distribution report defined by ASTM D 422.

Part 6: Standardization of the SDG

To assure that the SDG's ability to make consistent measurements has not been compromised, a daily measurement should be taken on a reference material and tracked day to day for any unacceptable variations. A metallic plate has been installed in the bottom of the SDG carrying case that is suitable for this purpose.

Although this verification is referred to as a standardization of the gauge, the results of the standardization in no way influence the measurement of the gauge, they only serve to alert the user to a change in the way that the gauge is operating. Unexpected changes in the standardization values should be noted and discussed with Product Service at TransTech.

From the Main Menu, select option 4 to standardize the SDG.

Main Menu

(1) Use Current Material
  DK BR SAND W GR
(2) Material Selection Menu
(3) Setup Menu
(4) Standardize Gauge
(5) Data Storage and Reporting

Standardize Measurement

Please move gauge to location

ENTER to Take Measurements
Menu to Abort

Make sure the SDG is sitting properly in its carrying case and select ENTER to begin the standardization.   The SDG's base plate should be wiped clean of debris with a dry cloth and placed in the case such that the white plastic standoff ring is in uniform contact with the standardization plate.

Your SDG and its carrying case/standardization plate are a matched set. The standardization should only be done if the SDG is with its original carrying case.

The SDG will take 5 consecutive measurements on the standardization plate and display an A and B value when it is finished.

Location 1 of 5

>>>>>>>>>>>>>>>>>>>>

Standardize Gauge

A: 0.8100
B: 0.0398

ENTER to Start Next Reading
0 to Exit to Main Menu

The A and B values should be recorded and compared to previous values to ensure that the electronics in the SDG have not drifted over time. You will be provided with specific calibration standards for your SDG. Expect typical variations in the A value of +/- 0.04 and typical variations in the B value of +/- 0.02.

If standardization values fall outside of the specified range call TransTech to discuss this with Product Service.

Part 7: Explanation of Gradation and Compaction Reports

All of the information needed to configure an SDG to measure the density and moisture content of a material is available on Compaction Test Reports (Proctor Test) and Particle Size Distribution Reports (Gradation/Sieve Analysis) completed as outlined by ASTM D 422 and ASTM D 1557. In order to configure the gauge to operate on materials that have high clay and silt contents, results from an Atterberg limits test (ASTM D 4318) will be needed as well.

Preview Material

Soil ID: 08.0527
Description: Dark Brown Sand
Max Dry Dens: 129.9
Opt Moisture: 7.6
PL: 0.0
LL: 0.0
Cu: 4.4
Cc: 0.94
UP/DOWN to Scroll

Preview Material
%Gravel: 6.4
%Fines: 6.0
%Sand: 87.6
%Greater than 3 in.: 0.0
%Greater than ¾ in.: 1.3

UP/DOWN to Scroll
0 to Exit to Material Menu
ENTER to Edit Material

The thirteen properties that will need to be entered through the SDG's user interface are shown on the Preview Material Screens above and defined below. Further definitions of these properties can be found in **Part 5** of the SDG Operators Handbook. Examples of a gradation report and compaction test are on the following pages

The **Soil ID** is any identifier that can associate the material being evaluated with its test report. A report number or sample number should be entered here. For the example shown, 08.0527 is the Soil ID. **Do not enter letters or characters as part of the Soil ID.**

The **Description** should be a used to describe the material and help make a visual association with the material being tested. Dark Brown Sand is used for this example.

The **Max Dry Density** is the maximum practically achievable density a soil can have. This value is determined experimentally by performing a "Proctor" Test (ASTM D 1557). 129.9 pounds per cubic foot is taken directly from the example compaction test report.

The **Optimum Moisture Content** is the water content (%) at which the material can be compacted to its maximum dry density. This is determined experimentally by performing a "Proctor" Test (ASTM D 1557). 7.6% is taken directly from the example compaction test report.

PL and **LL** are the plastic and liquid limits used to describe the plasticity of materials with a high silt and clay content. They are determined by following the test procedure outlined by ASTM D 4318. This example is a sandy material so PL and LL are input as 0.0. If plasticity tests had been performed on this material, the results would be given on the gradation report.

Cu and **Cc** are the Coefficient of Uniformity and Coefficient of Curvature of the material. They are calculated values that are typically used describe the particle size distribution a soil. In this example, Cu = 4.4 and Cc = 0.94

% Gravel is the summation of the coarse and fine gravel in a sample of material. Some gradation test results will report this as a single value while others will break it down into the coarse and fine fractions. The SDG only recognizes the total percentage of gravel so the coarse and fine fractions will need to be added together before entering them. The gradation report shown breaks the gravel content out into Fine and Coarse fractions so those will need to be added together. 1.3% + 5.1% = 6.4%

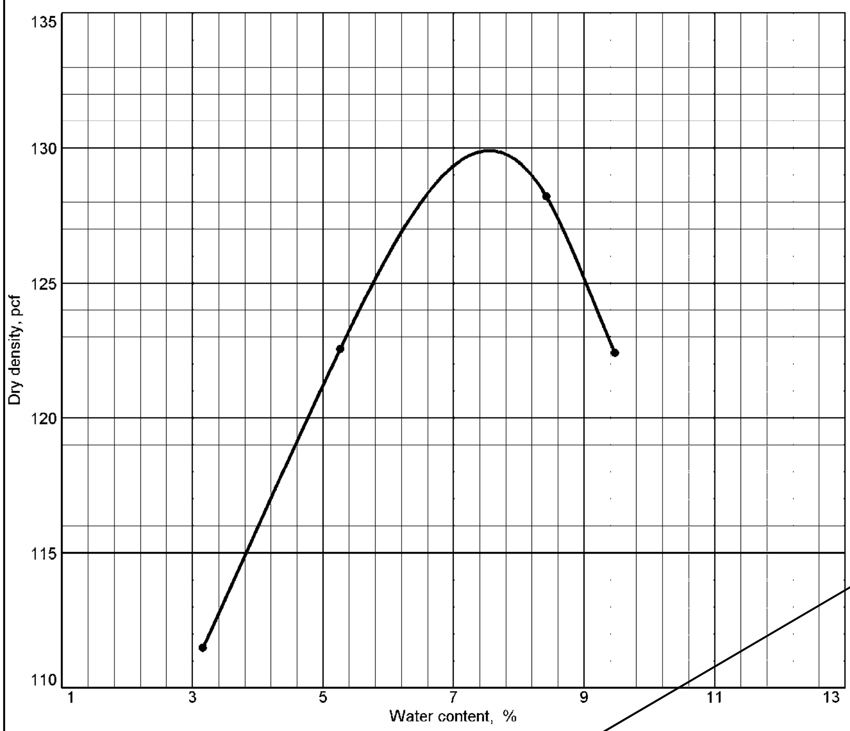
% Sand is the summation of the coarse, medium and fine sand in a sample of material. Some gradation test results will report this as a single value while others will break it down into the coarse, medium and fine fractions. The SDG only recognizes the total percentage of sand so the coarse, medium and fine fractions will need to be added together before entering them. The gradation report shown breaks the sand down into coarse, medium, and fine fractions, so the percent sand in the example shown is 8.1% + 31.3% +48.2% = 87.6%.

% Fines is the summation of the silt and clay in a sample of material. Some gradation test results will report this as a single value while others will break it down into the fractions of silt and clay. The SDG only recognizes the total percentage of fines so the coarse, silt and clay fractions will need to be added together before entering them. In this example, the percent fines is 6.0%.

% Greater than 3 inches is the percentage of the sample that is retained on the 3 inch sieve. Typical gradation tests report the "percent finer" or percentage that passes a particular sieve. In this example the percent finer for the 3 inch sieve is 100% so 0% of the sample is retained on the 3 inch sieve.

% Greater than 3/4 inch is the percentage of the sample that is retained on the 3/4 inch sieve. Typical gradation tests report the "percent finer" or percentage that passes a particular sieve. In this example the percent finer for the 3/4 inch sieve is 98.7% so 1.3% of the sample is retained on the 3/4 inch sieve.

COMPACTION TEST REPORT



Test specification: ASTM D 1557-00 Method A Modified

Elev/ Depth	Classification		Nat. Moist.	Sp.G.	LL	PI	% > No.4	% < No.200
	USCS	AASHTO						
							6.4	6.0

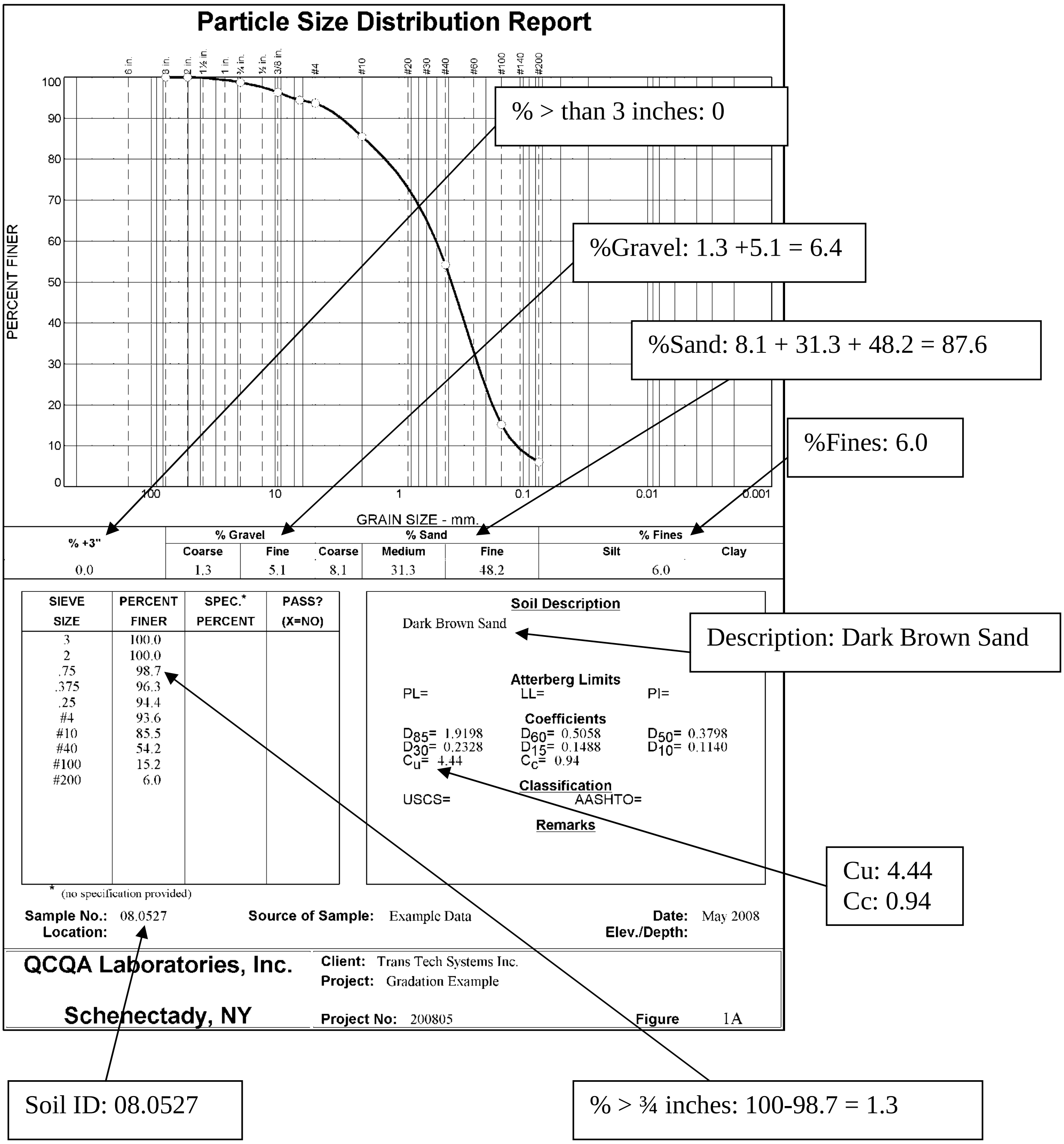
TEST RESULTS	MATERIAL DESCRIPTION
Maximum dry density = 129.9 pcf Optimum moisture = 7.6 %	Dark Brown Sand
Project No. 200805 **Client:** Trans Tech Systems Inc. **Project:** Gradation Example ● **Source:** Example Data **Sample No.:** 08.0527	**Remarks:**
QCQA Laboratories, Inc. **Schenectady, NY**	**Figure** 1A

Max Dry Density: 129.9

Opt Moisture: 7.6

Soil ID: 08.0527

Description: Dark Brown Sand



Particle Size Distribution Report

% +3"	% Gravel Coarse	% Gravel Fine	% Sand Coarse	% Sand Medium	% Sand Fine	% Fines Silt	% Fines Clay
0.0	1.3	5.1	8.1	31.3	48.2	6.0	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
3	100.0		
2	100.0		
.75	98.7		
.375	96.3		
.25	94.4		
#4	93.6		
#10	85.5		
#40	54.2		
#100	15.2		
#200	6.0		

* (no specification provided)

Soil Description

Dark Brown Sand

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 1.9198 D_{60}= 0.5058 D_{50}= 0.3798
D_{30}= 0.2328 D_{15}= 0.1488 D_{10}= 0.1140
C_u= 4.44 C_c= 0.94

Classification

USCS= AASHTO=

Remarks

Sample No.: 08.0527 **Source of Sample:** Example Data **Date:** May 2008
Location: **Elev./Depth:**

QCQA Laboratories, Inc. **Client:** Trans Tech Systems Inc.
Project: Gradation Example

Schenectady, NY **Project No:** 200805 **Figure** 1A

!! Note: The sum of %Greater the 3 inches, %Gravel, %Sand, and %Fines must add up to 100%. The default values programmed in the SDG software add up to 100%. As soon as one of those values is edited, the sum will no longer add up to 100% and an error message will be displayed until all of those gradation values are entered such that the sum is 100% again.!!

SDG Beta Unit Warranty

The Company warrants to the Purchaser that the product delivered hereunder will be free from defects in material or workmanship and to be the kind and quality designated or specified in the contract or purchase order. This warranty shall apply only to defects appearing within one (1) years from the date of shipment by the Company.

If the product delivered hereunder does not meet the above warranty and if the Purchaser promptly notifies the Company, the Company shall thereupon correct any defect, including nonconformance with the specification, either (at the Company's option) by repairing any defective or damaged parts of the product, replacing the product, or by making available the necessary repaired or replacement parts.

The liability of the Company under this warranty, for any loss, whether the claim is based on contract or negligence, shall not in any case exceed the cost of correcting defects in the product as herein provided, and upon the expiration of the warranty period, all such liability shall terminate. The foregoing shall constitute the exclusive remedy of the Purchaser and the exclusive liability of the Company. The foregoing warranty is exclusive and in lieu of all other warranties, whether written, oral, implied or statutory.

No warranty of merchantability or of fitness for proposed shall apply. Unauthorized service shall void this warranty.

Factory authorized service and replacement items may be obtained directly from TransTech's factory or through an authorized representative.

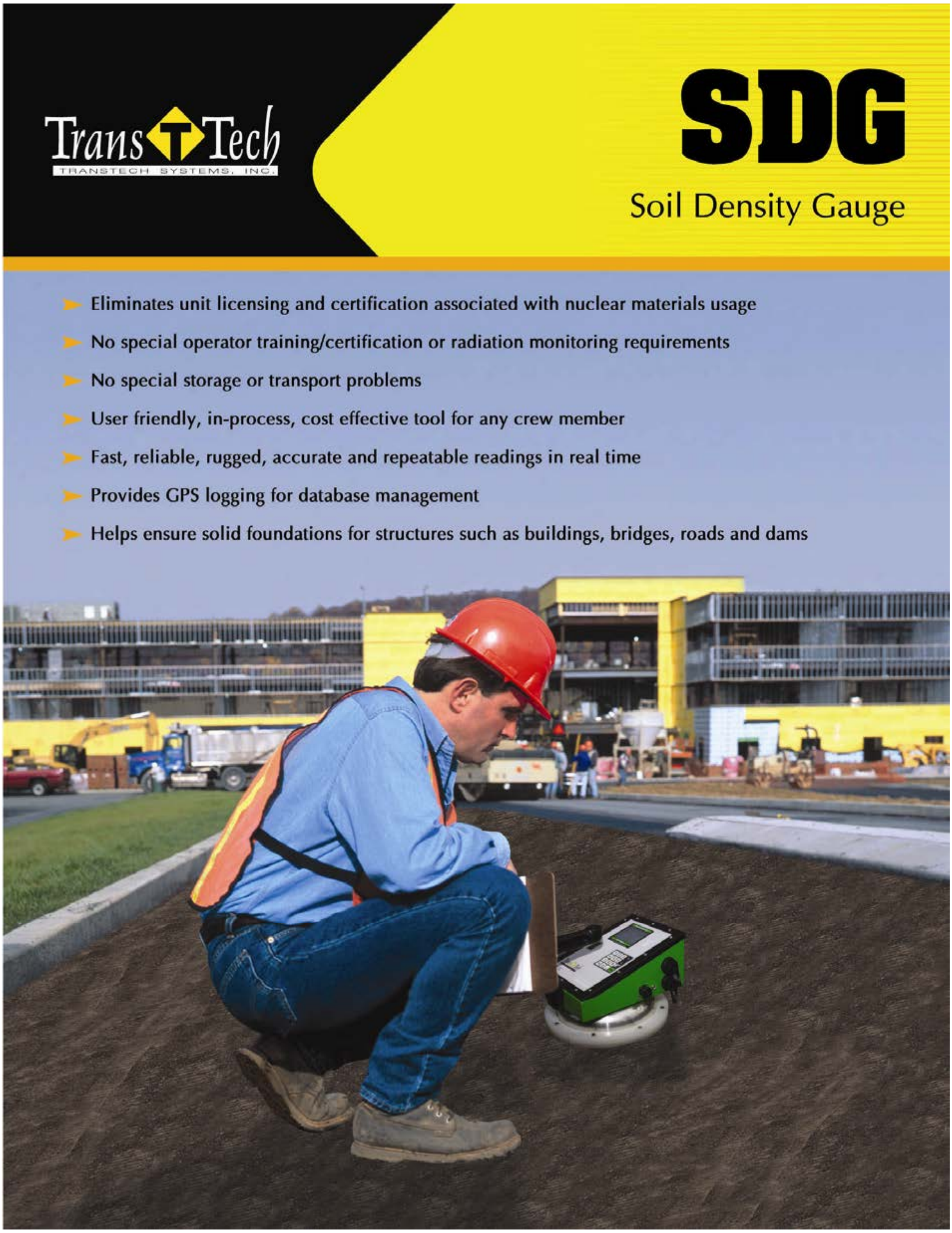
For further information contact TransTech Customer Service:

Telephone: (518) 370-5558 or
Toll Free in the US : 1 (800)724-6306
FAX: (518)370-5538
E-mail: sales @transtechsys.com
Address: TransTech Systems Inc.
1594 State Street
Schenectady, New York 12304

APPENDIX H

TransTech SDG Sales Brochure (Front Page Only)

Appendix H. TransTech SDG Sales Brochure (Front Page Only)



APPENDIX H

Earth Products China Sales Brochure Featuring the SDG (Front Page Only)

Appendix I. Earth Products China Sales Brochure (Front Page Only)