Non-Nuclear Compaction Gauge Comparison Study
Final Report

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State of Vermont
Agency of Transportation
Materials and Research Section

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1.0 INTRODUCTION

The following report summarizes the Certification and Independent Assurance Unit's efforts in conducting a comparison study of performance and usability between a nuclear compaction gauge and two non-nuclear compaction gauge alternatives. During the course of the 2007 construction season, in cooperation with Program Development's Construction Section and Operations' Maintenance Section, various materials were tested for in-place moisture and density. The various materials tested were used in both roadway subbases and structural backfills. The Certification and Independent Assurance Units' interest in the non-nuclear compaction gauge alternatives is two-fold. First, they are capable of being transported and used anywhere without the concerns and regulations associated with nuclear safety, and second, they do not accrue the substantial financial costs associated with the ownership of nuclear compaction gauges. These costs include training and certifications for technicians, semi-annual leak tests, yearly verifications, and bi-annual calibrations; along with licensing, storage, special handling, and shipping of a hazardous material.

2.0 NON-NUCLEAR COMPACTION GAUGE EQUIPMENT

2.1 Moisture and Density Indicator

The first piece of equipment, provided for use was the Moisture and Density Indicator or M+DI by Durham Geo Slope Indicator. M+DI, see Figure 1 for a picture of the apparatus, utilizes Time Domain Reflectometry (TDR) technology. Time Domain

Figure 1: Moisture and Density Indicator (M+DI)

Reflectometry is used to measure the travel time of an electromagnetic step pulse produced by the TDR pulse generator through four soil spikes in the ground. The four spikes are driven into the ground in a specified geometry that is governed by the use of a template. The spikes are 0.75 inches in diameter and are available in below ground lengths of 4, 6, and 8 inches (spikes with a below ground length of 6 inches were used in this comparison evaluation). 1.250 additional inches (includes the 0.250 inch thickness of the spike head) are above ground to accommodate the thickness of the template. These spikes are visible in Figure 2. The voltage signal is analyzed by a personal digital assistant (PDA) running specially developed algorithms to determine apparent dielectric constant and bulk electrical conductivity of the soil. The software uses a set of equations to relate these two properties to water content and density which are displayed on the screen of a laptop or hand-held computer.[1]

Figure 2: Typical TDR test set-up

2.2 Electrical Density Gauge

Figure 3: EDG Apparatus

The second non-nuclear compaction testing device is the Electrical Density Gauge (EDG) model "B" which was provided for the Agency's use by Electrical Density Gauge, LLC and can be purchased through the Humboldt Manufacturing Company. The EDG is a portable, battery-powered instrument which determines the density, moisture content, and percent compaction of soil. The EDG, see Figure 3, measures the electrical dielectric properties and moisture levels of the compacted soil using high a radio-frequency traveling between four darts driven through a template into the soil being tested. The electrical current is measured between the darts and recorded by the data collection unit. The darts come in 4, 6, 8, 10, and 12 inch lengths and are tapered to ensure a continual positive contact with the soil being (darts with a below ground length of 6 inches were used in this comparison evaluation). The EDG relates the measured electrical current to certain physical properties of the soil.[2] The soil models for the EDG can be obtained in the field during the compaction process, see Figure 4.

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[1] Durham Geo Slope Indicator, M+D Indicator, 2005, rev. May 2007, <http://www.durhamgeo.com/pdf/m_test-pdf/soil/m+di%20brochure.pdf>

[2] Humboldt Manufacturing Co., Soil-Field, Compaction, Moisture/Density, Electrical Density Gauge, <http://www.humboldtmfg.com/pdf/section/8-9.pdf>


Figure 4: Typical EDG test set-up

3.0 INVESTIGATION

3.1 Overview

Both the Electrical Density Gauge, LLC Company and Durham Geo Slope Indicator provided on-site training for Vermont Agency of Transportation personnel. Resident Engineers, Regional Soils Technicians, and District Technicians notified the Certification and Independent Assurance Unit of opportunities to conduct the testing. It was not the intent to provide oversight or acceptance testing relative to field compaction. All compaction tests associated with this effort were investigative and used for research purposes only. Conscientious efforts were made to try to limit interferences with the Contractor's placement efforts. The compaction tests were conducted on roadway subbases and structural backfills. Sand borrow and a 1 ½" minus crushed aggregate were tested as roadway subbase materials. Granular backfill for structures and subbase of gravel were tested as structural backfill materials.

3.2 Soil Model Development

Both gauges require a soil model to allow the instrument to use the constructed algorithms to determine the dry density of the soil. The effort to determine the soil models for both instruments were conducted in both field and laboratory settings. At the time of this research, the EDG required that a soil model be developed solely in the field during the compaction process, while the soil model for the M+DI unit can be "built" in the laboratory either before or after the field compaction testing. For the purposes of our research we elected to perform the soil model for the M+DI equipment in the laboratory after the field investigation using in-place material sampled from the project.

The soil model for the EDG is constructed by measuring the field compaction efforts. At different compactive efforts and moisture contents, a compaction test is run using the nuclear gauge after which a compaction measurement is made with the EDG within the nuclear gauge footprint.

Step-by-step instructions given by the EDG menu were followed to begin building the soil model. The first step involved placing the dart template on the soil and hammering the four darts into the corresponding holes. Electrodes from the EDG were attached to the four darts in sequence as detailed by the EDG's step-by-step menu, a temperature probe is placed into the soil, and readings are taken. The density and moisture content readings from the nuclear gauge were imputed into the EDG and used to develop the soil model.

For the development of the M+DI soil model, the compacted material was sampled in-place and transported back to the Materials & Research Laboratory for the development of a moisture-density curve in a laboratory. A typical moisture density curve was constructed in accordance with T-99 or T-180 using the four inch mold provided with the M+DI laboratory kit. Once the soil had been compacted in the mold, a center rod was driven through a template into the center of the compacted soil. The template was removed and a ring collar was placed on top of the mold and the coaxial head assembly used in the field test was placed on top of the ring collar with the three outside prongs resting on the ring collar and the center prong resting on the center rod. The coaxial head assembly was connected to the pulse generator. The voltage signal was then analyzed by a PDA running specially developed algorithms resulting in a compaction point. Once four to five points have been developed, a compaction curve is produced which will indicated the maximum density at optimum moisture for that material.

3.3 Procedures Used to Determine Field Compaction for Comparison Purposes

The overall procedure was to perform two in-place moisture/in-place density tests using the nuclear gauge and record the results. The nuclear gauge rod containing a nuclear source was driven 6 inches into the material. Neutrons emitted by the source penetrate the material and are thermalized. Thermalization is the process where neutrons are slowed to the point where further collisions with hydrogen or other materials will not continue to slow the neutron. The detectors in the gauge base are sensitive to thermalized neutrons but are insensitive to non-thermalized or "fast" neutrons and, as a result, the counts obtained are directly proportional to the amount of hydrogen/moisture present in the material. The detectors also measure the radiation emitted by the source. Gamma photons reaching the detectors must first pass through the material, colliding with the electrons present in the material. The lower the number of photons that reach the detectors, the higher is the material density.[3] The nuclear gauge was rotated 180 degrees and another in-place moisture/in-place density test was conducted. The first test was recorded as Nuclear Gauge Test A and the second test as Nuclear Gauge Test B as diagramed in Figure 5.

[3] Troxler, Manual of Operation and Instruction – Model 3430 Surface Moisture Density Gauge (North Carolina: Troxler, 2001) 2-2, 2-5.

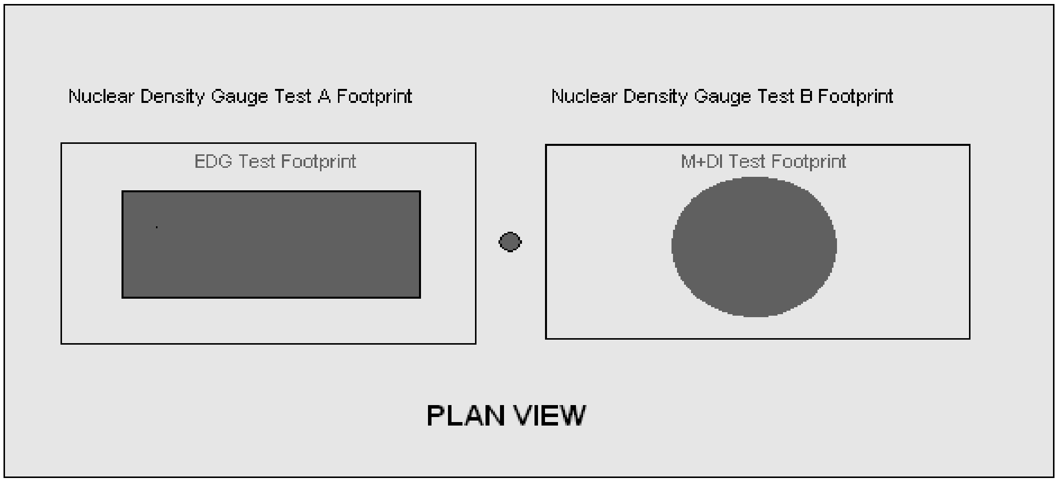

Figure 5: Typical Plan View of Testing Layout

Following the compaction tests using the nuclear gauge the technician created a "jobsite" within the EDG and assigns the associated soil model to it. The EDG is then placed within the footprint of Nuclear Gauge Test A and a compaction test was completed, being careful to keep the influence of the test from intersecting the hole left from the pin of the nuclear gauge. The same step-by-step procedure used in building the EDG soil model was used for performing the in-place moisture and density test.

The M+DI unit was then placed within the footprint of Nuclear Gauge Test B and a compaction test was conducted, being careful to keep the influence of the non-nuclear compaction test from intersecting the hole left from the pin of the nuclear gauge.

4.0 RESULTS

The field data for the EDG and the M+DI, along with their corresponding nuclear density gauge readings are presented in Excel spreadsheets in Appendix A. Figures 6 and 7 display the results of the compaction testing conducted in Footprints A and B, respectively. These scatter graphs show a 1:1 ratio for the nuclear density gauge meaning that a dry density of 125 pcf reported by the nuclear density gauge on the x-axis is also equivalent to 125 pcf on the y-axis. The EDG and M+DI compaction values are reported on the y-axis with the nuclear gauge compaction values on the x-axis

The moisture content of the soil was also evaluated using each device and in similar fashion to that as described previously. Figures 8 and 9 display the relationship of the nuclear gauge to the EDG and M+DI, respectively.

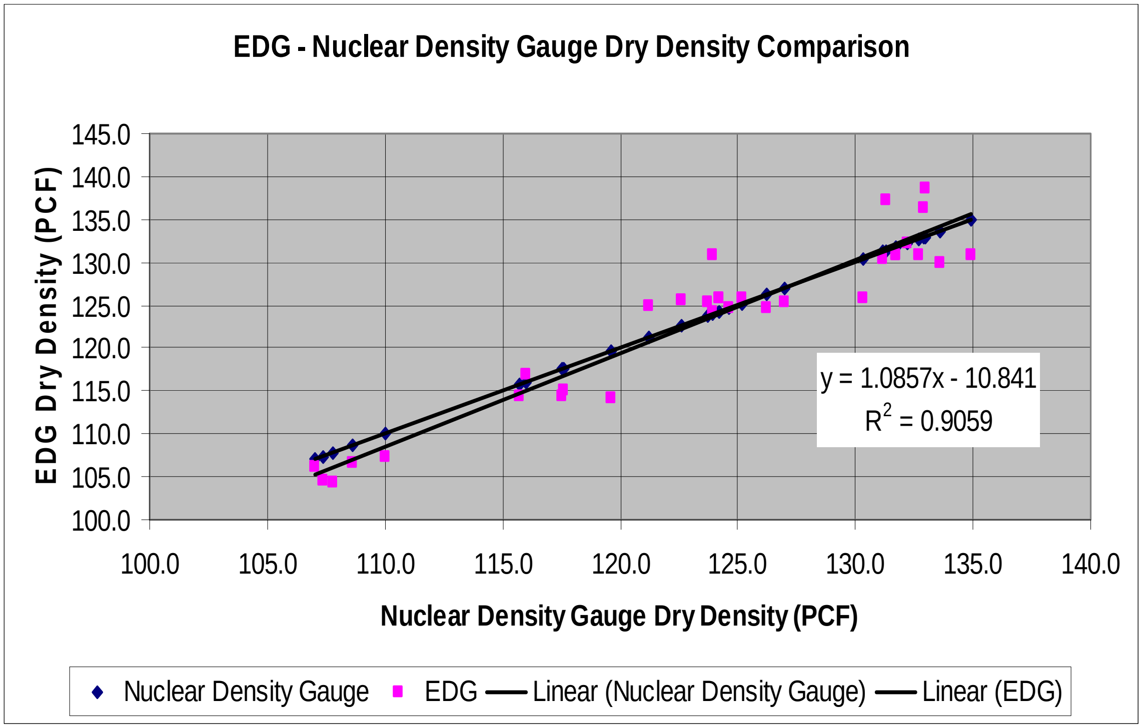

Figure 6: In-Place Dry Density: EDG vs. Nuclear Density Gauge

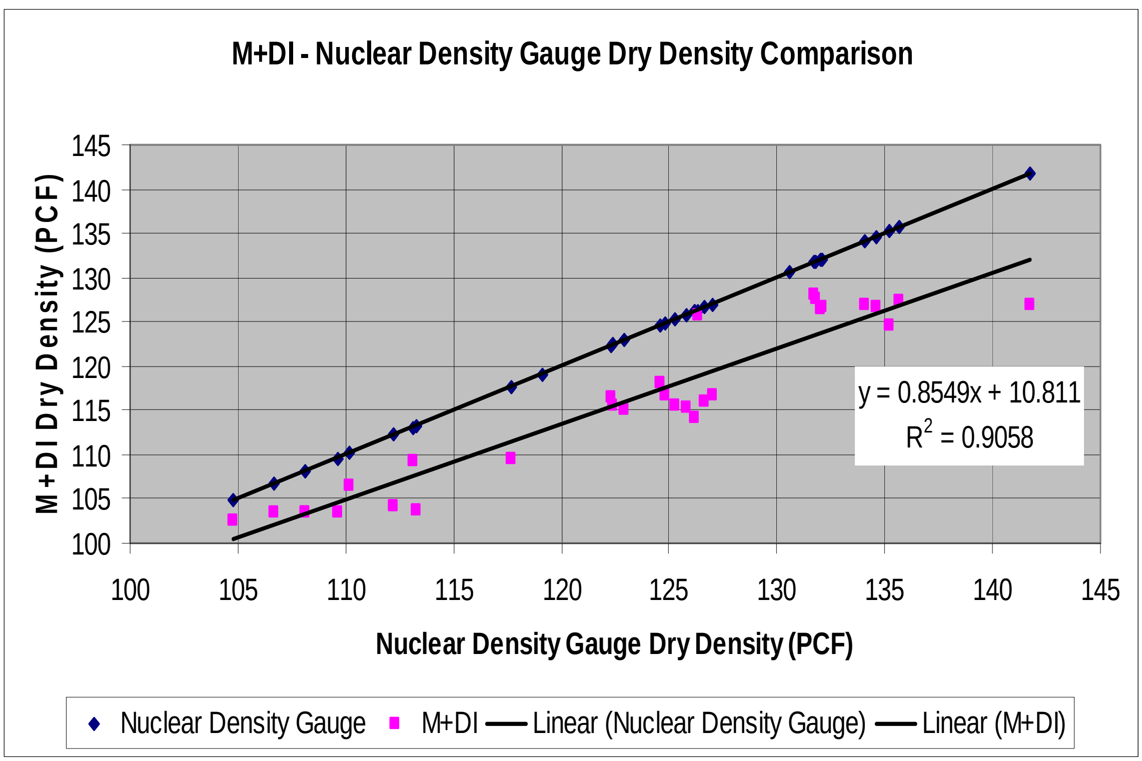

Figure 7: In-Place Dry Density: M+DI vs. Nuclear Density Gauge

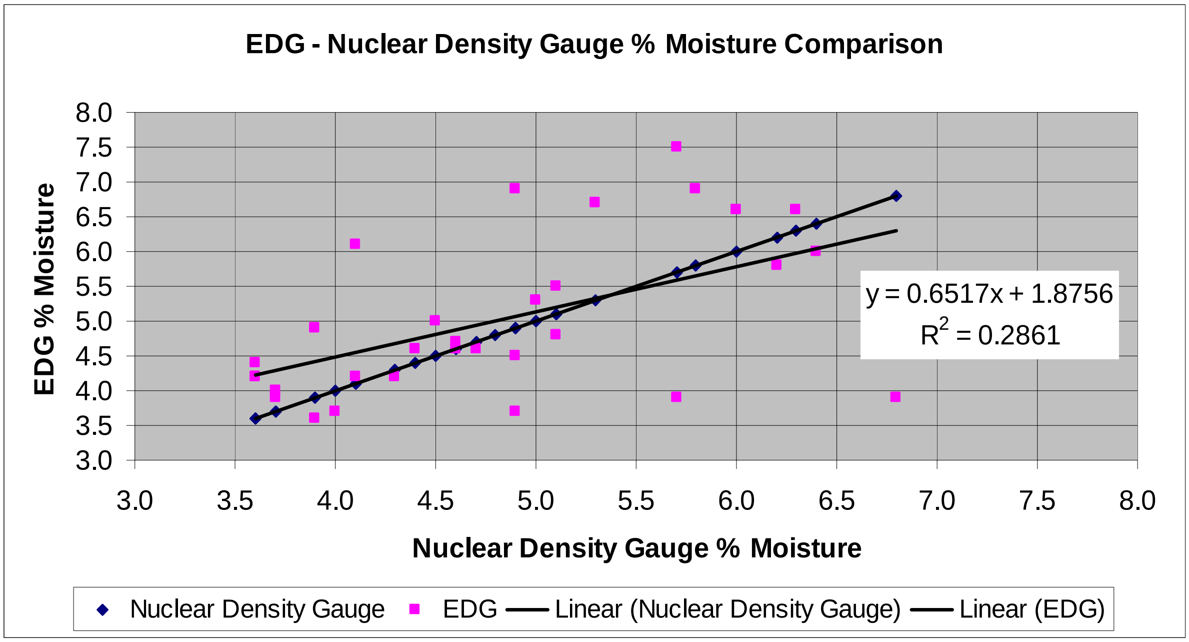

Figure 8: Moisture Content: EDG vs. Nuclear Density Gauge

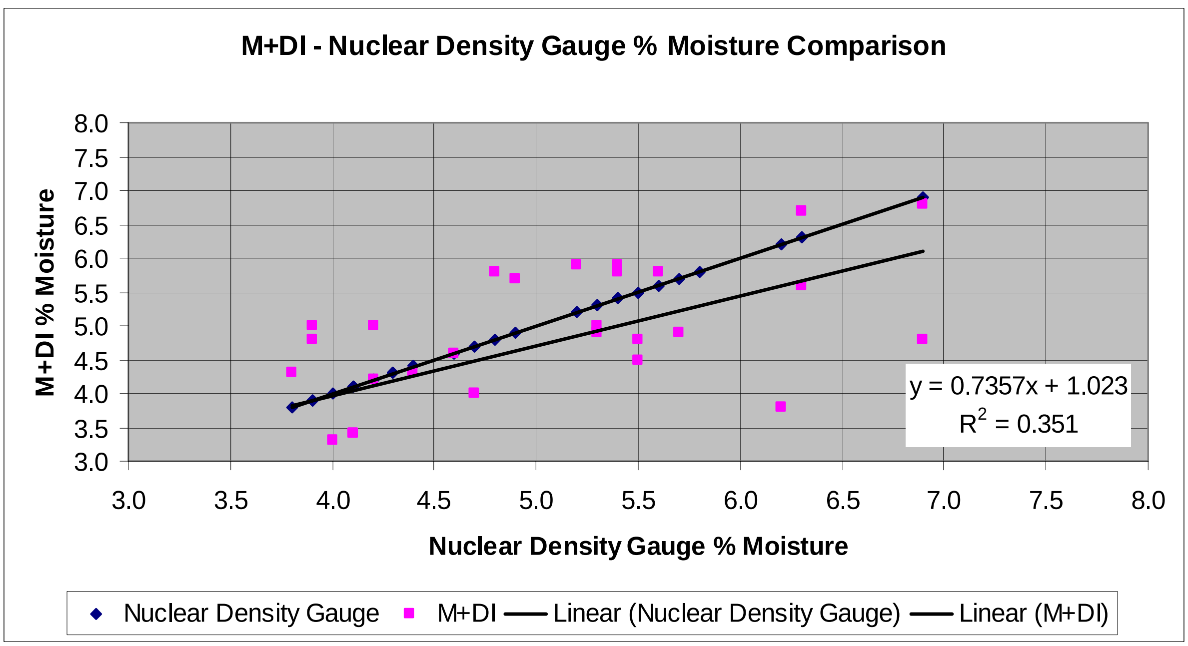

Figure 9: Moisture Content: M+DI vs. Nuclear Density Gauge

5.0 ANALYSES

In regards to the in-placed dry density comparisons, the EDG compared well with the Nuclear Density Gauge; especially with the fine grained material such as the sand borrow. Both the EDG and the M+DI exhibited linear relationships with an R-value of 0.90; however, the M+DI results showed consistently lower in-placed dry density readings compared to the Nuclear Density Gauge. It can be speculated that the process required to obtain field readings with the M+DI (driving four spikes, six or eight inches long, into an area about eight inches in diameter) is more disruptive to the compacted soil than the EDG therefore loosening the compacted soil resulting in a lower value for the in-place dry density.

Figures 8 and 9 show how the field moisture contents for the EDG and M+DI relate to the values obtained using the Nuclear Density Gauge. Both the EDG and the M+DI showed a somewhat linear relationship with R-values of 0.29 and 0.35. This is a weak relationship most likely due to the variability of moisture content within the different soil types and different depths of the soil. Neither the EDG nor the M+DI show a favorable comparison trend with the Nuclear Density Gauge in either a coarse or fine grained material.

6.0 RECOMMENDATIONS / SUGGESTIONS

6.1 Apparatus

Both the EDG and the M+DI were time consuming to set up, and not easily transported around a job site. While the nuclear gauge uses a single spike, both the EDG and the M+DI utilize four spikes that are driven into the ground to determine the soil properties. This increases the likelihood of hitting a rock and disturbing the compacted soil four fold.

In addition, the four spikes for the TDR are driven through a template in a very concentrated area (about eight inches). This setup did not work well in coarse material. The spikes themselves are prone to bending and "mushroom" when significant resistance is met such as rocks in the soil or densely compacted subgrade material. If the template could be larger in diameter to spread the spikes out and the spikes themselves could be tapered and fabricated out of heavier gauge steel, that would avoid some of the compacted soil disruption and alleviate the bending and mushrooming of the spikes.

The darts for the EDG however are tapered to allow them to easily deflect off of stones when driven into the ground and are more robust in design. The process of attaching the electrodes to the darts, however, is time consuming since you have to reattach the electrodes four times in sequence. If a single reading could be obtained by attaching the four electrodes only once then this would be a more productive and efficient process.

6.2 Soil Model Development

The building of the soil model process for the M+DI is similar to the process of the Nuclear Density Gauge; a moisture-density curve is established in a lab and is used to establish a relationship with the field data to give percent moisture and percent compaction. The EDG used in this study requires a soil model to be built in the field as explained in section 2.2. This process for building a soil model in the field took a long time to do and has the potential to interfere with the Contractor's compaction efforts. A Nuclear Density Gauge is required in this process; therefore there is no efficiency gained by using the EDG. It is understood that a new soil model system has been developed and may be evaluated by this Agency in 2008.

6.3 Transport

The M+DI and EDG can not be transported around a job site very easily; they have too many loose parts that require multiply trips to move from one spot to the next. Consolidation of all the pieces into one unit would facilitate transport around would save a lot of time and effort in the process. For the M+DI the answer may be combine the pulse generator with the hand-held computer into one unit. For the EDG, simply developing a caddy of sort to hold the EDG, template, darts, hammer, and electrodes would be an improvement.

7.0 CONCLUSIONS

The results of the dry densities recorded by the two non-nuclear compaction gauges indicated a good correlation with the Nuclear Density Gauge. The results of the moisture content of the in-place material showed variability. The sources of this variability should be determined. Therefore, an analysis of actual in-place moisture contents should be conducted to verify the results and determine the inherent variability of the nuclear gauge and not simply assume that the nuclear gauge's moisture content values are correct.

Both non nuclear density gauges showed that the technology available today does show some promise, but that there are issues to resolve from both a results and field application perspective. More testing and research is needed to establish sufficient confidence in the algorithms employed by each of these technologies.

APPENDIX A

TDR / EDG AND NUCLEAR DENSITY GAUGE COMPARISON FIELD DATA

TDR FIELD DATA

JOB SITE INFORMATION		TDR				NUCLEAR DENSITY GAUGE					Difference Reported between Nuclear Gauge and EDG				
DATE	MATERIAL	WET DENSITY, PCF	DRY DENSITY, PCF	% MOISTURE	% COMPACTION	WET DENSITY, PCF	DRY DENSITY, PCF	% MOISTURE	% COMPACTION	% COMPACTION w/STONE CORRECTION FACTOR	WET DENSITY	DRY DENSITY	% MOISTURE	% COMPACTION	% COMPACTION w/STONE CORRECTION FACTOR
09/10/2007 Mon	Subbase of Gravel	133.1	126.8	5.0	95.8	149.1	141.7	5.3	106.7	104.3	16.0	14.9	0.3	10.9	8.5
09/10/2007 Mon	Subbase of Gravel	131.5	125.8	4.5	95.1	133.2	126.3	5.5	95.1	93.0	1.7	0.5	1.0	0.0	2.1
09/10/2007 Mon	Subbase of Gravel		**NO DATA**			138.2	130.6	5.8	98.3	96.2			**NO DATA**		
09/10/2007 Mon	Subbase of Gravel	129.2	124.5	3.8	94.0	143.6	135.2	6.2	101.8	99.6	14.4	10.7	2.4	7.8	5.6
09/10/2007 Mon	Subbase of Gravel	132.4	126.4	4.8	95.5	141.1	132.0	6.9	99.4	97.2	8.7	5.6	2.1	3.9	1.7
09/10/2007 Mon	Subbase of Gravel	135.2	128.1	5.6	96.7	140.0	131.7	6.3	99.2	97.0	4.8	3.6	0.7	2.5	0.3
09/11/2007 Tue	Granular Backfill for Structures	125.1	118.2	5.9	93.2	131.1	124.6	5.2	98.3	96.1	6.0	6.4	0.7	5.1	2.9
09/11/2007 Tue	Granular Backfill for Structures	119.8	115.1	4.0	90.8	128.7	122.9	4.7	96.9	94.8	8.9	7.8	0.7	6.1	4.0
09/11/2007 Tue	Granular Backfill for Structures	120.6	115.6	4.3	91.2	130.8	125.3	4.4	98.8	96.7	10.2	9.7	0.1	7.6	5.5
09/11/2007 Tue	Granular Backfill for Structures	122.1	116.5	4.8	91.9	127.1	122.3	3.9	96.5	94.4	5.0	5.8	0.9	4.6	2.5
09/11/2007 Tue	Granular Backfill for Structures		**NO DATA**			131.1	126.2	3.9	99.5	97.4			**NO DATA**		
09/11/2007 Tue	Granular Backfill for Structures		**NO DATA**			123.8	119.1	3.9	93.9	91.9			**NO DATA**		
09/11/2007 Tue	Granular Backfill for Structures	120.2	115.4	4.2	91.0	131.1	125.8	4.2	99.2	97.1	10.9	10.4	0.0	8.2	6.1
09/11/2007 Tue	Granular Backfill for Structures	122.6	116.7	5.0	92.1	131.9	127.0	3.9	100.2	98.0	9.3	10.3	1.1	8.1	5.9
09/11/2007 Tue	Granular Backfill for Structures	120.6	115.6	4.3	91.1	127.0	122.4	3.8	96.5	94.4	6.4	6.8	0.5	5.4	3.3
09/11/2007 Tue	Granular Backfill for Structures	121.5	116.1	4.6	91.6	132.4	126.6	4.6	99.8	97.7	10.9	10.5	0.0	8.2	6.1
09/11/2007 Tue	Granular Backfill for Structures	122.6	116.8	5.0	92.1	130.0	124.8	4.2	98.4	96.3	7.4	8.0	0.8	6.3	4.2
09/11/2007 Tue	Granular Backfill for Structures	118.0	114.1	3.4	90.0	131.3	126.2	4.1	99.5	97.4	13.3	12.1	0.7	9.5	7.4
09/19/2007 Wed	Sand Borrow	109.4	103.4	5.8	93.6	114.2	108.1	5.6	97.8	**N/A**	4.8	4.7	0.2	4.2	**N/A**
09/19/2007 Wed	Sand Borrow	107.7	102.6	4.9	92.9	110.3	104.8	5.3	94.8	**N/A**	2.6	2.2	0.4	1.9	**N/A**
09/19/2007 Wed	Sand Borrow	109.4	103.4	5.8	93.6	115.5	109.6	5.4	99.2	**N/A**	6.1	6.2	0.4	5.6	**N/A**
09/19/2007 Wed	Sand Borrow	109.3	103.4	5.7	93.5	111.9	106.7	4.9	96.6	**N/A**	2.6	3.3	0.8	3.1	**N/A**
09/19/2007 Wed	Sand Borrow	109.6	103.5	5.9	93.6	114.0	108.1	5.4	97.8	**N/A**	4.4	4.6	0.5	4.2	**N/A**
09/19/2007 Wed	1 1/2" Crusher Run	130.5	126.9	2.8	94.3	139.5	134.1	4.1	99.6	97.4	9.0	7.2	1.3	5.3	3.1
09/19/2007 Wed	1 1/2" Crusher Run	131.6	127.4	3.3	94.7	141.2	135.7	4.0	100.7	98.5	9.6	8.3	0.7	6.0	3.8
09/19/2007 Wed	1 1/2" Crusher Run	130.0	126.7	2.6	94.2	140.4	134.6	4.3	99.9	97.7	10.4	7.9	1.7	5.7	3.5
09/21/2007 Fri	1 1/2" Crusher Run	131.8	127.5	3.4	94.8	137.1	131.8	4.1	97.8	95.7	5.3	4.3	0.7	3.0	0.9
09/21/2007 Fri	1 1/2" Crusher Run	129.7	126.6	2.5	94.1	137.8	132.1	4.3	98.1	95.9	8.1	5.5	1.8	4.0	1.8
10/01/2007 Mon	Granular Backfill for Structures	116.9	109.4	6.8	92.5	125.9	117.7	6.9	99.5	94.6	9.0	8.3	0.1	7.0	2.1
10/01/2007 Mon	Granular Backfill for Structures	116.6	109.2	6.7	92.3	120.3	113.1	6.3	95.6	90.9	3.7	3.9	0.4	3.3	1.4
10/01/2007 Mon	Granular Backfill for Structures	109.3	104.2	4.9	88.0	118.5	112.2	5.7	94.8	90.2	9.2	8.0	0.8	6.8	2.2
10/01/2007 Mon	Granular Backfill for Structures	108.7	103.7	4.8	87.7	119.5	113.3	5.5	95.8	91.1	10.8	9.6	0.7	8.1	3.4
10/01/2007 Mon	Granular Backfill for Structures	112.6	106.5	5.8	90.0	115.5	110.2	4.8	93.2	88.6	2.9	3.7	1.0	3.2	1.4
										Average Difference	**7.75**	**7.03**	**0.78**	**5.52**	**3.59**
										Standard Deviation	**3.61**	**3.18**	**0.59**	**2.44**	**2.12**
										Max	16.00	14.90	2.40	10.90	8.54
										Min	1.70	0.50	0.00	0.01	0.28
										Mean = 3*STDEV	18.58	16.58	2.55	12.84	9.94

EDG FIELD DATA

Project / Job Information						EDG				NUCLEAR DENSITY GAUGE					Difference Reported between Nuclear Gauge and EDG				
DATE	TIME	JOB SITE	SOIL MODEL	MATERIAL	TEST	WET DENSITY, PCF	DRY DENSITY, PCF	% MOISTURE	% COMPACTION	WET DENSITY, PCF	DRY DENSITY, PCF	% MOISTURE	% COMPACTION	% COMPACTION w/STONE CORRECTION FACTOR	WET DENSITY	DRY DENSITY	% MOISTURE	% COMPACTION	% COMPACTION w/STONE CORRECTION FACTOR
09/10/2007 Mon	11:27:49A	JS006	SM008	Subbase of Gravel	FT001	138.37	130.78	5.8	100.43	139.9	131.7	6.2	99.17	96.98	1.53	0.92	0.40	1.26	3.45
09/10/2007 Mon	12:03:15P	JS006	SM008	Subbase of Gravel	FT002	139.62	130.95	6.6	100.56	131.7	123.9	6.3	93.30	91.24	7.92	7.05	0.30	7.26	9.32
09/10/2007 Mon	12:22:50P	JS006	SM008	Subbase of Gravel	FT003	140.24	130.49	7.5	100.21	138.6	131.2	5.7	98.80	96.61	1.64	0.71	1.80	1.41	3.60
09/10/2007 Mon	12:48:14P	JS006	SM008	Subbase of Gravel	FT004	139.87	130.8	6.9	100.44	142.7	134.9	5.8	101.58	99.34	2.83	4.10	1.10	1.14	1.10
09/10/2007 Mon	1:01:10P	JS006	SM008	Subbase of Gravel	FT005	139.59	130.91	6.6	100.53	140.6	132.7	6	99.92	97.72	1.01	1.79	0.60	0.61	2.81
09/10/2007 Mon	1:31:06P	JS006	SM008	Subbase of Gravel	FT006	138.59	130.8	6	100.44	140.1	131.7	6.4	99.17	96.98	1.51	0.90	0.40	1.27	3.46
09/11/2007 Tue	11:08:29A	JS009	SM009	Granular Backfill for Structures	FT001	131.84	125.84	4.8	99	131.5	125.2	5.1	98.74	96.60	0.34	0.64	0.30	0.26	2.40
09/11/2007 Tue	11:12:23A	JS009	SM009	Granular Backfill for Structures	FT002	131.58	125.66	4.7	99.6	128.2	122.6	4.6	96.69	94.60	3.38	3.06	0.10	2.91	5.00
09/11/2007 Tue	11:52:21A	JS009	SM009	Granular Backfill for Structures	FT003	131.58	125.78	4.6	99.7	129.9	124.2	4.6	97.95	95.83	1.68	1.58	0.00	1.75	3.87
09/11/2007 Tue	12:08:19P	JS009	SM009	Granular Backfill for Structures	FT004	129.89	124.71	4.2	98.85	130.8	126.2	3.6	99.53	97.38	0.91	1.49	0.60	0.68	1.47
09/11/2007 Tue	12:40:52P	JS009	SM009	Granular Backfill for Structures	FT005	130.01	124.8	4.2	98.92	126.4	121.2	4.3	95.58	93.52	3.61	3.60	0.10	3.34	5.40
09/11/2007 Tue	12:46:50P	JS009	SM009	Granular Backfill for Structures	FT006	129.72	124.77	4	98.9	128.6	124.6	3.7	98.26	96.14	1.12	0.17	0.30	0.64	2.76
09/11/2007 Tue	1:10:51P	JS009	SM009	Granular Backfill for Structures	FT007	129.13	124.29	3.9	98.52	128.4	123.9	3.7	97.71	95.60	0.73	0.39	0.20	0.81	2.92
09/11/2007 Tue	1:14:52P	JS009	SM009	Granular Backfill for Structures	FT008	130.57	125.32	4.2	99.33	131.6	127	3.6	100.16	97.99	1.03	1.68	0.60	0.83	1.34
09/11/2007 Tue	1:18:42P	JS009	SM009	Granular Backfill for Structures	FT009	129.89	**No Data**	**No Data**	**No Data**	128.5	123.7	3.9	97.56	95.45	1.39	**No Data**	**No Data**	**No Data**	**No Data**
09/11/2007 Tue	1:30:18P	JS009	SM009	Granular Backfill for Structures	FT010	131.95	125.84	4.9	99.74	130	124.2	4.9	97.95	95.83	1.95	1.64	0.00	1.79	3.91
09/11/2007 Tue	1:33:49P	JS009	SM009	Granular Backfill for Structures	FT011	131.32	125.7	4.5	99.63	135	130.3	3.6	102.76	100.54	3.68	4.60	0.90	3.13	0.91
09/11/2007 Tue	1:39:20P	JS009	SM009	Granular Backfill for Structures	FT012	130.84	125.31	4.4	99.33	129.2	123.7	4.5	97.56	95.45	1.64	1.61	0.10	1.77	3.88
09/19/2007 Wed	10:01:31A	JS011	SM011	Sand Borrow	FT001	112.75	107.42	5	100.98	115.8	110	5.3	99.55	**N/A**	3.05	2.58	0.30	1.43	**N/A**
09/19/2007 Wed	10:52:53A	JS011	SM011	Sand Borrow	FT002	111.62	104.64	6.7	98.36	112.7	107.4	4.9	97.19	**N/A**	1.08	2.76	1.80	1.17	**N/A**
09/19/2007 Wed	11:05:15A	JS011	SM011	Sand Borrow	FT003	111.57	104.35	6.9	98.08	113.3	107.8	5.1	97.56	**N/A**	1.73	3.45	1.80	0.52	**N/A**
09/19/2007 Wed	11:18:37A	JS011	SM011	Sand Borrow	FT004	112.09	106.26	5.5	99.88	112.4	107	5	96.83	**N/A**	0.31	0.74	0.50	3.05	**N/A**
09/19/2007 Wed	11:29:18A	JS011	SM011	Sand Borrow	FT005	112.33	106.65	5.3	100.25	113.9	108.6	4.9	98.28	**N/A**	1.57	1.95	0.40	1.97	**N/A**
09/19/2007 Wed	11:55:27A	JS011	SM012	1 1/2" Crusher Run	FT006	142.15	137.12	3.7	105.77	136.5	131.3	4	97.48	95.35	5.65	5.82	0.30	8.29	10.42
09/19/2007 Wed	12:16:58P	JS011	SM012	1 1/2" Crusher Run	FT007	141.33	136.24	3.7	105.09	138.1	132.9	3.9	98.66	96.51	3.23	3.34	0.20	6.43	8.58
09/19/2007 Wed	12:32:22P	JS011	SM012	1 1/2" Crusher Run	FT008	143.67	138.71	3.6	106.99	138.8	133	4.4	98.74	96.59	4.87	5.71	0.80	8.25	10.40
09/21/2007 Fri	11:00:40A	JS011	SM012	1 1/2" Crusher Run	FT009	135.76	129.83	4.6	100.14	139	133.6	4.1	99.18	97.02	3.24	3.77	0.50	0.96	3.12
09/21/2007 Fri	11:23:25A	JS011	SM012	1 1/2" Crusher Run	FT010	137.68	132.13	4.2	101.92	137.6	132.2	4.1	98.14	96.01	0.08	0.07	0.10	3.78	5.91
10/01/2007 Mon	6:18:27A	JS012	SM013	Granular Backfill for Structures	FT001	124.03	116.93	6.1	101.7	123.9	116	6.8	98.06	93.25	0.13	0.93	0.70	3.64	8.45
10/01/2007 Mon	8:27:13A	JS012	SM013	Granular Backfill for Structures	FT002	129.83	114.28	13.6	99.39	124.3	117.5	5.7	99.32	94.45	5.53	3.22	outlier removed[1]	0.07	4.94
10/01/2007 Mon	8:37:58A	JS012	SM013	Granular Backfill for Structures	FT003	118.76	114.28	3.9	99.39	121.1	115.7	4.7	97.80	93.01	2.34	1.42	0.80	1.59	6.38
10/01/2007 Mon	8:55:25A	JS012	SM013	Granular Backfill for Structures	FT004	118.69	114.21	3.9	99.33	125.6	119.6	5	101.10	96.14	6.91	5.39	1.10	1.77	3.19
10/01/2007 Mon	9:10:03A	JS012	SM013	Granular Backfill for Structures	FT005	120.43	115.18	4.6	100.18	123.2	117.6	4.8	99.41	94.53	2.77	2.42	0.20	0.77	5.65
														Average Difference	**2.44**	**2.48**	**0.56**	**2.33**	**4.62**
														Standard Deviation	**1.94**	**1.81**	**0.51**	**2.25**	**2.75**
														Max	7.92	7.05	1.80	8.29	10.42
														Min	0.08	0.07	0.00	0.07	0.91
														Mean = 3*STDEV	8.25	7.92	2.08	9.08	12.88

Notes: [1] **Outlier value was 7.9 which is more than three standard deviations from the mean.**