Assessment of Drilled Shaft Capacity and QA/QC from Measuring While Drilling BED31-977-09

GRIP Meeting

FDOT Project Manager:
Dino Jameson, P.E.

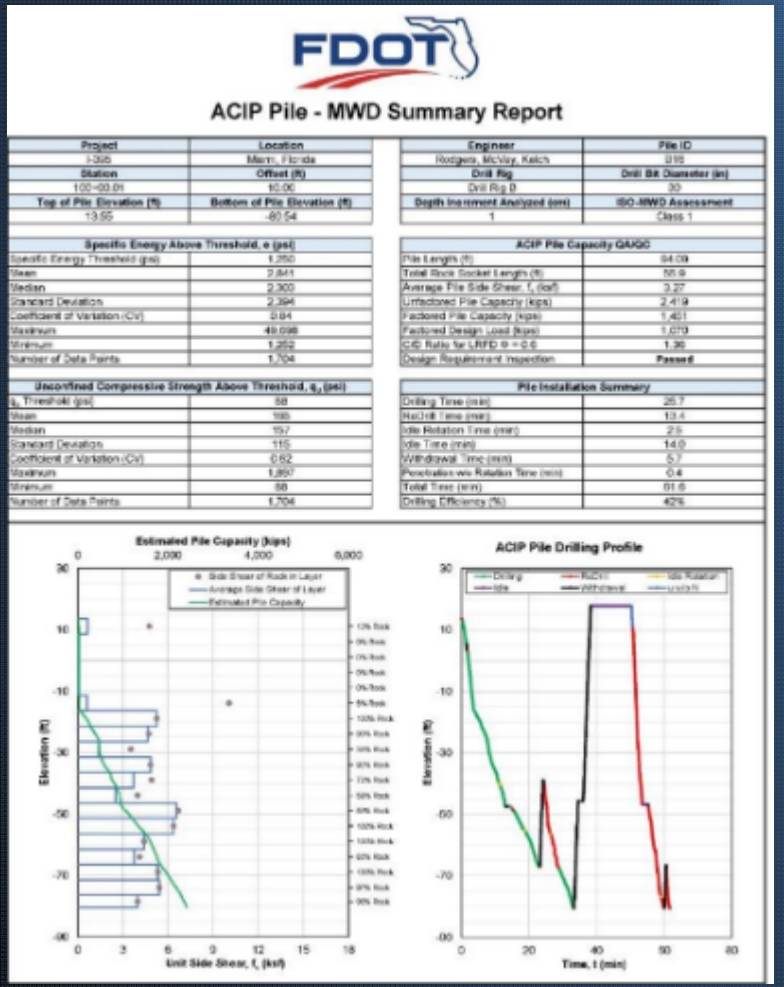
UF Project Investigator:
Michael Rodgers, Ph.D., P.E.

Graduate Researcher:
Wyatt Kelch, Ph.D.

August 14, 2025

Project Background

- FDOT investigated the use of MWD for Auger Cast Piles (ACP) to provide QA/QC during pile installations in Miami-Dade
  - BDV31-977-125
- A new analysis tool was developed
  - Transformed time-referenced data collected from AME to depth-referenced data that is compatible for MWD strength assessment
- For ACPs, a time-referenced data format collected from AME is most commonly used in Florida, and the ACP analysis tool was developed specifically to accommodate the data format



Project Background

- For drilled shaft MWD…
  - Time-referenced data
  - Depth-referenced data
  - Both data formats
- A new analysis tool needed to be developed to accommodate the possible variations in raw data recording and reporting
- Provide the FDOT with a reliable method of drilled shaft QA/QC analysis, regardless of the monitoring system used
  - Contractors can utilize a variety of MWD systems
- On-site and remote monitoring should be explored to improve the quality control portion of the of the QA/QC tool
  - Providing real time strength assessments that can be viewed by all stakeholders

Project Objectives

1. Using FDOT MWD criteria (FM 5-625), develop a versatile data analysis tool that will be used to provide drilled shaft MWD QA/QC
2. Conduct a feasibility study to identify the requirements of providing on-site and remote monitoring capabilities to enhance the QA/QC method
3. Monitor at least one load tested shaft and three production shafts at three independent sites to develop correlations for QA/QC purposes
4. Provide a QA/QC report for all shafts monitored during the research
5. Compare test results with previously derived correlations

Tasks and Deliverables

- Deliverable 1 – Establish drilled shaft MWD data reduction criteria and procedures (Task 1)
- Deliverable 2 – On-site and remote monitoring implementation feasibility study (Task 2)
- Deliverable 3 – MWD specific energy vs. drilled shaft side shear correlation (Task 3)
- Deliverable 4 – MWD correlation validation for drilled shaft QA/QC (Task 4)
- Deliverable 5a - Draft Final (Task 5)
- Deliverable 5b - Closeout Meeting (Task 5)
- Deliverable 6 - Final Report (Task 6)

Task 1a – Development of Specification Language

- UF Researchers submitted draft spec language for Drilled Shaft MWD:
- FDOT Standard Specifications for Road and Bridge Construction – Section 455
  - Section 455-15.1.2 – Drilled Shaft Installation Plan (DSIP)
  - Section 455-15.1.3.1 – Measuring While Drilling (MWD)
  - Section 455-15.10.5 – MWD Equipment
  - Section 455-15.10.6 – MWD Measurements
- Florida Method of Test (FM 5-625)
  - Section 3.6.1 – Minimum Accuracy of Measured Values

Task 1b - New MWD System - LiM's PocketLiM

Task 1b – Development of the Data Analysis Tool – Beta Version

- The monitoring systems onboard the drilled shaft drill rigs, and the format in which the drilling parameters may be recorded and reported were unknown
- New raw data processing criteria and procedures needed to be developed to accommodate the data, regardless of the format
  - Data layout
  - File type
    - e.g., .xlsx, .csv, .txt, .guh, etc.
- The research team considered:
  - Prior MWD data collected in various formats
  - Obtained sample drilling data from commercial vendors
  - Simulated large data sets (1 million rows of data)
    - 20 hrs of drilling at 16 Hz (MWD system max)
  - Investigated multiple file types for reported data
- Allowed UF to develop initial processing criteria and a preliminary analysis tool (Beta Version)
  - 5th iteration of Beta version in use in S. Florida for ACPs

Raw Data Variations Based on MWD System

Time (s)	Depth (feet)	Penetration Rate (ft/min)	RPM (rev/min)	Torque pressure (psi)	Crowd pressure (psi)	Crowd Force (Tf)	Bottom Grout (psi)	Top Grout pressure (psi)	Grout Flow (yd3/h)	Grout Volume yd3
0.00	0.000	0.00	0.00	116.03	406.10	0.183	45.122	3.881091138	0	0
0.00	0.000	0.00	0.00	111.20	402.48	0.176	45.097	4.39633378	0	0
2.37	0.082	0.54	0.00	111.33	408.06	1.826	45.133	4.606430907	0	0
2.56	0.157	20.85	0.00	116.03	406.10	4.572	45.017	4.608424711	0	0
2.75	0.236	23.92	0.00	116.03	410.94	4.978	45.058	4.654531436	0	0
3.01	0.312	16.72	0.00	116.03	413.36	4.807	45.049	4.624562065	0	0
3.14	0.397	28.84	0.00	116.03	406.10	4.725	45.001	4.583066013	0	0
3.39	0.479	14.80	0.00	112.40	416.98	4.816	45.045	4.704096164	0	0
3.59	0.551	20.33	0.00	101.53	406.10	6.433	45.040	4.377891091	0	0
3.78	0.627	22.90	0.00	140.20	406.10	5.865	44.924	3.953709229	0	0
3.97	0.696	22.90	0.00	328.75	454.45	6.040	44.934	3.958319901	0	0
4.23	0.771	15.19	0.00	681.67	732.44	6.009	44.966	3.94679322	0	0
4.42	0.840	18.97	0.00	1005.59	1256.99	6.020	45.035	3.87993847	0	0
4.61	0.909	21.53	0.00	841.21	1165.13	5.836	45.058	4.290288315	0	0
4.80	0.988	22.56	1.10	836.38	1131.29	5.892	44.994	4.66375278	0	0
5.06	1.056	16.34	3.30	997.13	1334.34	5.862	44.987	4.648768095	0	0
5.25	1.132	18.63	3.30	1213.48	1580.90	5.850	44.984	4.580760677	0	0
5.38	1.201	27.94	3.30	1319.84	1791.21	5.849	44.987	4.659142108	0	0
5.83	1.316	11.75	3.30	1429.65	1808.82	5.844	44.980	4.613694051	0	0

Time	Duration (min)	Gear Box RPM	Penetration Rate (ft/min)	Penetration Rat	Depth (ft)	Gear Box Pres	Torque (ft-lbs)	Crowd Pressur	Thrust (lb
6/10/2020 7:29:31 AM	0	-81.89	-46.9488204	3.048	0	639.0361062	0	221.0374548	3426.96
6/10/2020 7:29:32 AM	0.02	-82.5	-49.1469832	3.048	0	66.2822289	0	201.8924784	3130.14
6/10/2020 7:29:33 AM	0.03	-84.45	-51.2467208	3.048	0.0656168	0	0	44.8166493	694.837
6/10/2020 7:29:34 AM	0.05	-88.47	-53.0183744	3.048	0.0656168	664.9978545	0	213.0603813	3303.29
6/10/2020 7:29:35 AM	0.07	-80.52	-48.4908152	3.048	0.0656168	589.4332128	0	224.2282842	3476.44
6/10/2020 7:29:36 AM	0.08	11.97	1.0498688	0.9525	0.0984252	584.0668179	0	213.4954944	3310.03
6/10/2020 7:29:37 AM	0.1	12.45	1.6076116	0.622040816	0.164042	620.9063937	0	248.3045424	3849.71
6/10/2020 7:29:38 AM	0.12	14.51	1.8372704	0.544285714	0.1968504	691.1046405	0	253.2358242	3926.17
6/10/2020 7:29:39 AM	0.13	18.86	1.804462	0.554181818	0.2624672	653.5398762	0	256.4266536	3975.64
6/10/2020 7:29:40 AM	0.15	21.26	2.3950132	0.417534247	0.2952756	661.5169497	0	250.915221	3890.19
6/10/2020 7:29:41 AM	0.17	22.16	2.8543308	0.350344828	0.328084	652.66965	0	273.5411022	4240.98
6/10/2020 7:29:42 AM	0.18	22.64	2.8543308	0.350344828	0.3937008	653.1047631	0	280.3578741	4346.67
6/10/2020 7:29:43 AM	0.2	23.07	2.952756	0.338666667	0.4593176	691.9748667	0	259.1823699	4018.36
6/10/2020 7:29:44 AM	0.22	23.33	3.0183728	0.331304348	0.492126	686.8985472	0	258.6022191	4009.37
6/10/2020 7:29:45 AM	0.23	23.55	2.9855644	0.334945055	0.5577428	710.1045792	0	252.6556734	3917.17
6/10/2020 7:29:46 AM	0.25	23.7	2.952756	0.338666667	0.5905512	732.2953473	0	269.1899712	4173.52
6/10/2020 7:29:47 AM	0.27	24.06	2.9855644	0.334945055	0.6233596	678.776436	0	255.4113897	3959.9
6/10/2020 7:29:48 AM	0.28	24.24	2.8871392	0.346363636	0.6889764	694.5855453	0	254.8312389	3950.9
6/10/2020 7:29:49 AM	0.3	24.38	2.8543308	0.350344828	0.7217848	679.3565868	0	252.8007111	3919.42

```
[PARAMETER]
Date;Depth;P-Grout;P-Rotary Head;P-Crowd;Rotation;Torque;Speed;X-Axis;Y-Axis;Grout
0;m;bar;bar;bar;RPM;kNm;cm/min;°;°;l/min;L;%;-;-;-;%;l/min

[DATA]
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```
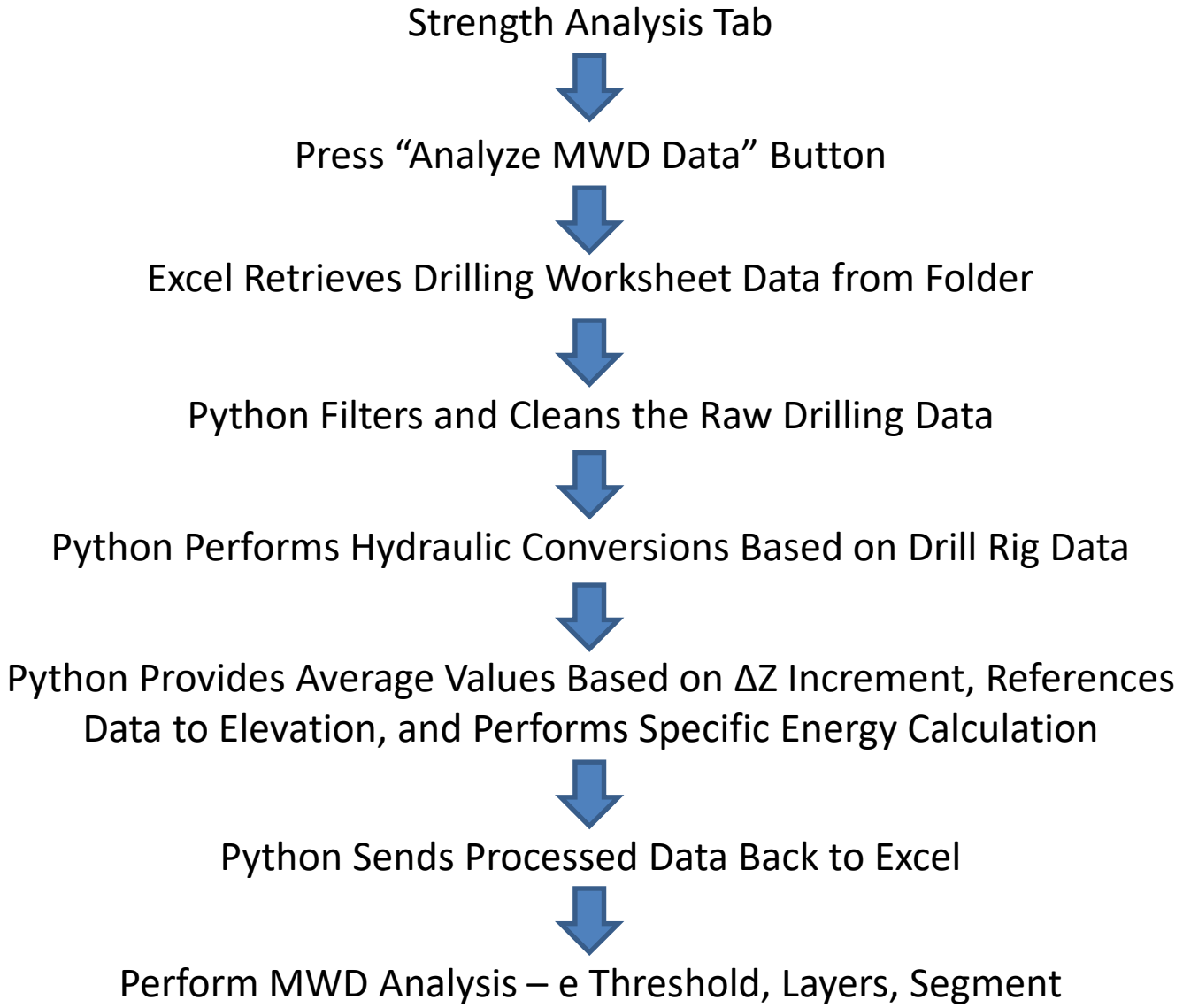
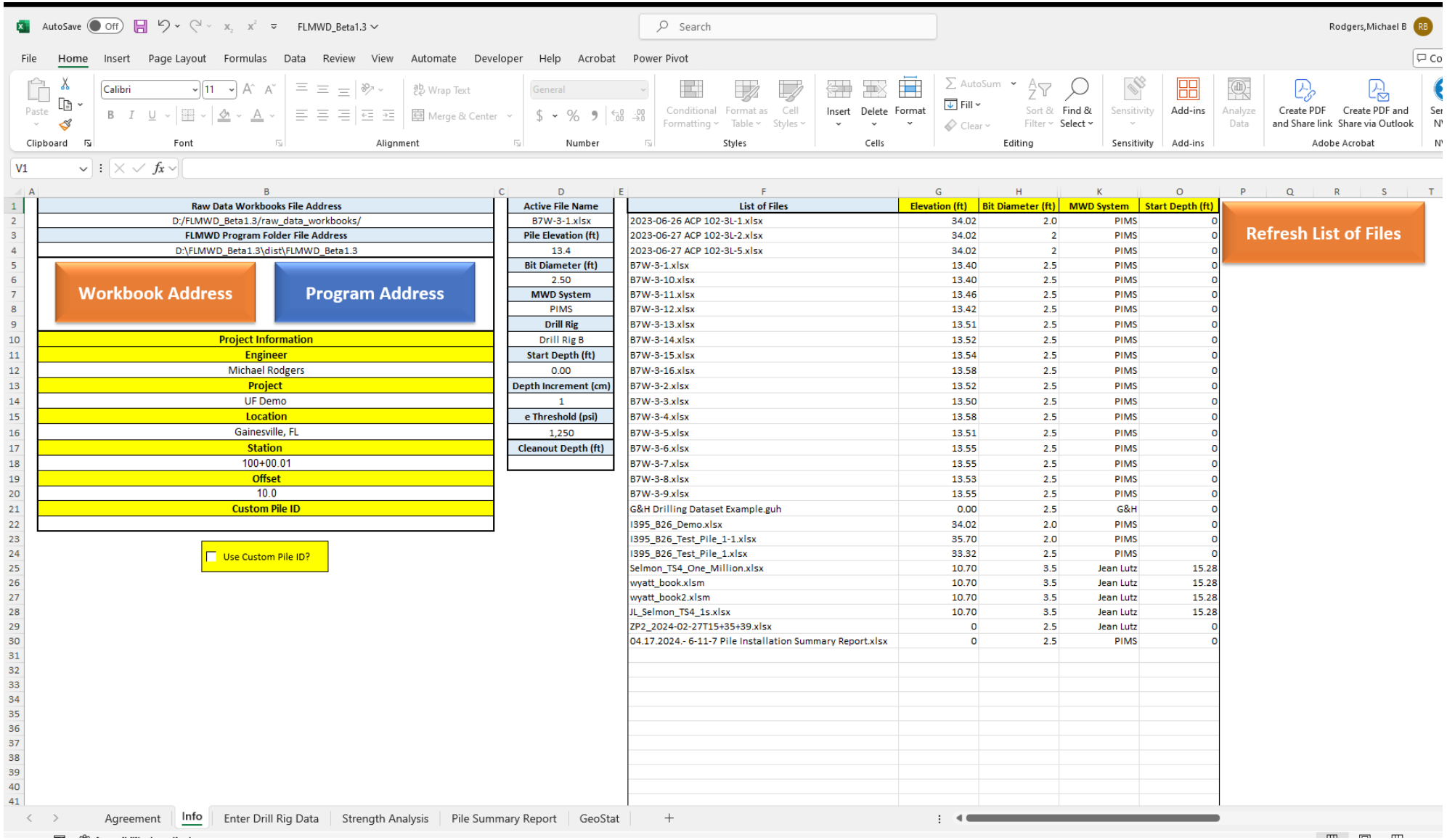

FLMWD Analysis Tool Workflow

- New MWD analysis tool utilizes python to perform the background calculations
  - No longer have to copy and paste data or files into analysis tool
    - Imports all data and files from folders
    - Never have to open a single drilling file to analyze your MWD data
  - Much smaller file sizes
    - > 3MB compared to 40 to 50 MB
  - Easier to track changes during upgrades and modifications
- Provides a similar user interface (UI) to ACIP analysis tool
  - Specific energy threshold and layers can be adjusted without triggering the program to reanalyze the data



Info Sheet



Raw Data Workbooks File Address
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FLMWD Program Folder File Address
D:\FLMWD_Beta1.3\dist\FLMWD_Beta1.3

Workbook Address | Program Address

Project Information
Engineer
Michael Rodgers
Project
UF Demo
Location
Gainesville, FL
Station
100+00.01
Offset
10.0
Custom Pile ID

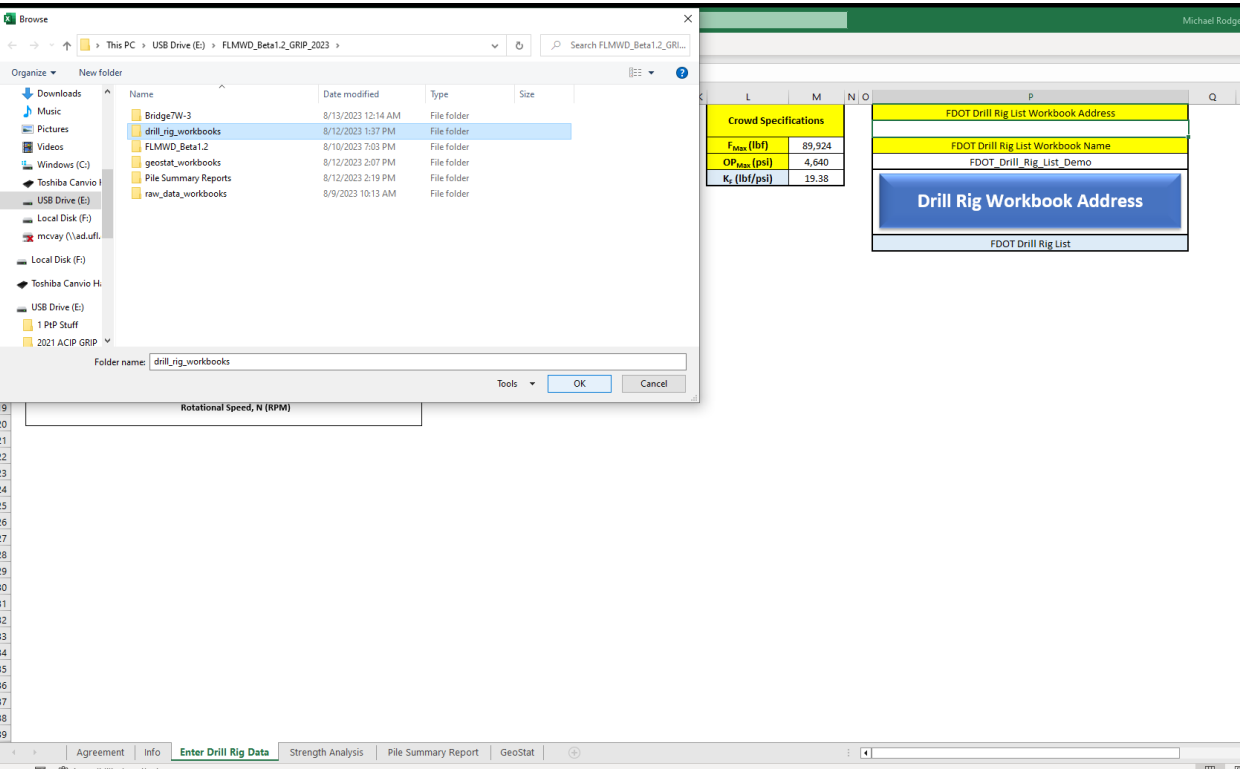
Use Custom Pile ID?

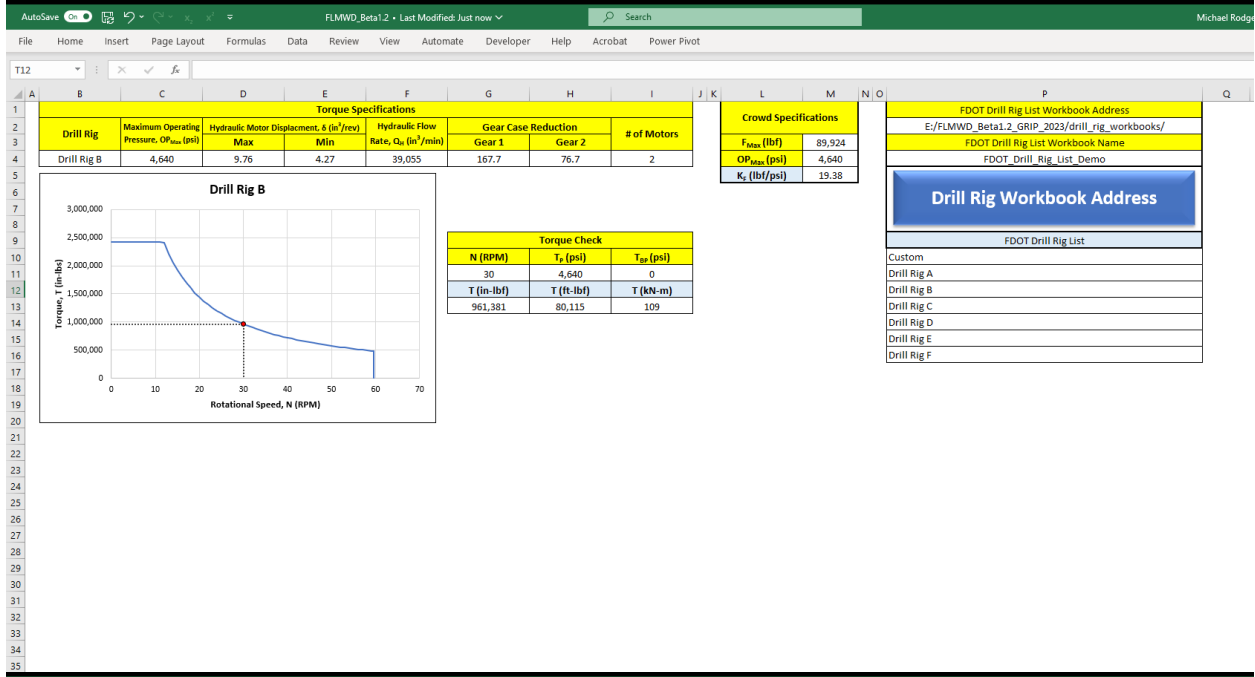
Active File Name
B7W-3-1.xlsx
Pile Elevation (ft)
13.4
Bit Diameter (ft)
2.50
MWD System
PIMS
Drill Rig
Drill Rig B
Start Depth (ft)
0.00
Depth Increment (cm)
1
e Threshold (psi)
1,250
Cleanout Depth (ft)

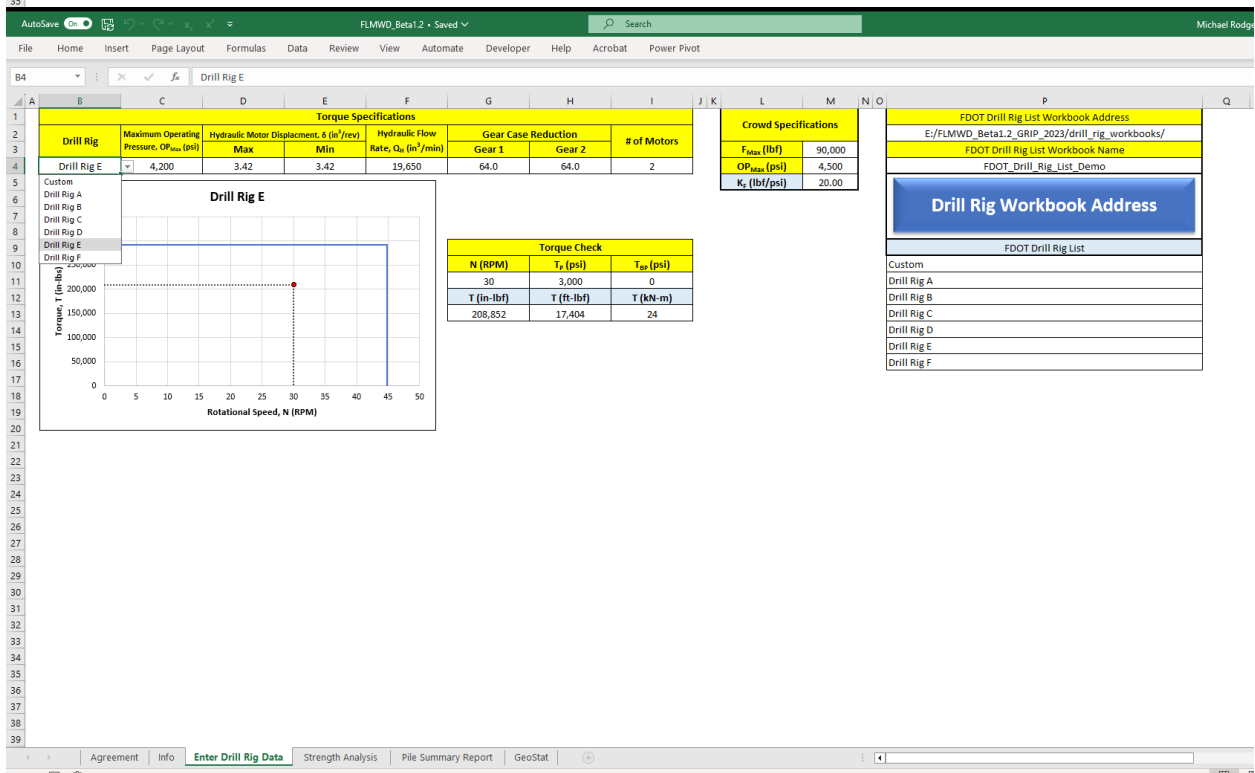
Refresh List of Files

List of Files	Elevation (ft)	Bit Diameter (ft)	MWD System	Start Depth (ft)
2023-06-26 ACP 102-3L-1.xlsx	34.02	2.0	PIMS	0
2023-06-27 ACP 102-3L-2.xlsx	34.02	2	PIMS	0
2023-06-27 ACP 102-3L-5.xlsx	34.02	2	PIMS	0
B7W-3-1.xlsx	13.40	2.5	PIMS	0
B7W-3-10.xlsx	13.40	2.5	PIMS	0
B7W-3-11.xlsx	13.46	2.5	PIMS	0
B7W-3-12.xlsx	13.42	2.5	PIMS	0
B7W-3-13.xlsx	13.51	2.5	PIMS	0
B7W-3-14.xlsx	13.52	2.5	PIMS	0
B7W-3-15.xlsx	13.54	2.5	PIMS	0
B7W-3-16.xlsx	13.58	2.5	PIMS	0
B7W-3-2.xlsx	13.52	2.5	PIMS	0
B7W-3-3.xlsx	13.50	2.5	PIMS	0
B7W-3-4.xlsx	13.58	2.5	PIMS	0
B7W-3-5.xlsx	13.51	2.5	PIMS	0
B7W-3-6.xlsx	13.55	2.5	PIMS	0
B7W-3-7.xlsx	13.55	2.5	PIMS	0
B7W-3-8.xlsx	13.53	2.5	PIMS	0
B7W-3-9.xlsx	13.55	2.5	PIMS	0
G&H Drilling Dataset Example.guh	0.00	2.5	G&H	0
I395_B26_Demo.xlsx	34.02	2.0	PIMS	0
I395_B26_Test_Pile_1-1.xlsx	35.70	2.0	PIMS	0
I395_B26_Test_Pile_1.xlsx	33.32	2.5	PIMS	0
Selmon_TS4_One_Million.xlsx	10.70	3.5	Jean Lutz	15.28
wyatt_book.xlsm	10.70	3.5	Jean Lutz	15.28
wyatt_book2.xlsm	10.70	3.5	Jean Lutz	15.28
JL_Selmon_TS4_1s.xlsx	10.70	3.5	Jean Lutz	15.28
ZP2_2024-02-27T15+35+39.xlsx	0	2.5	Jean Lutz	0
04.17.2024.- 6-11-7 Pile Installation Summary Report.xlsx	0	2.5	PIMS	0

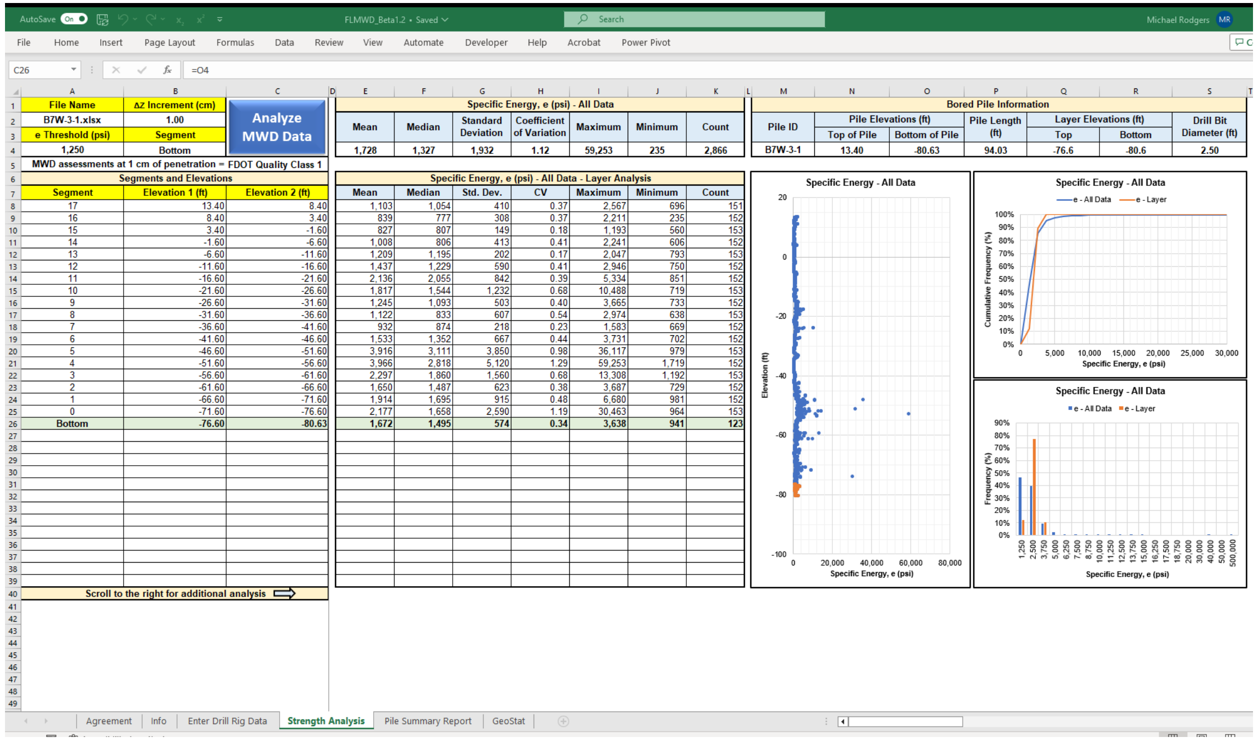
Enter Drill Rig Data

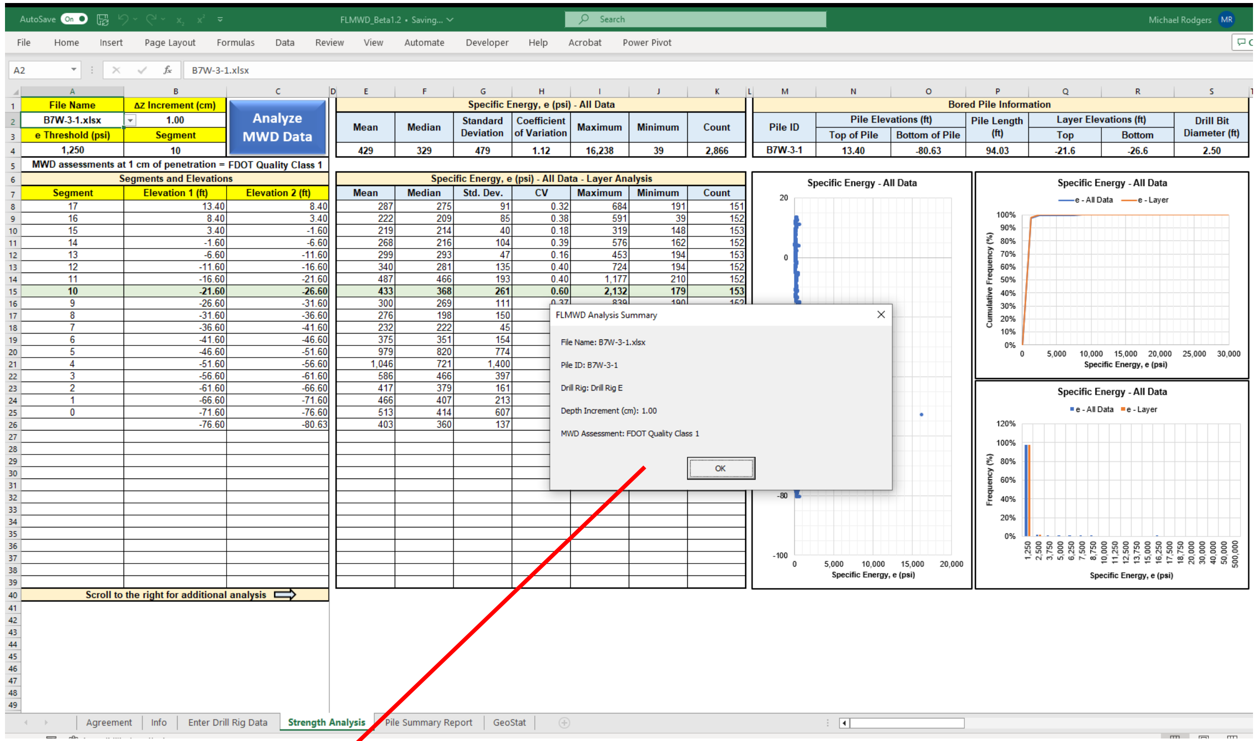


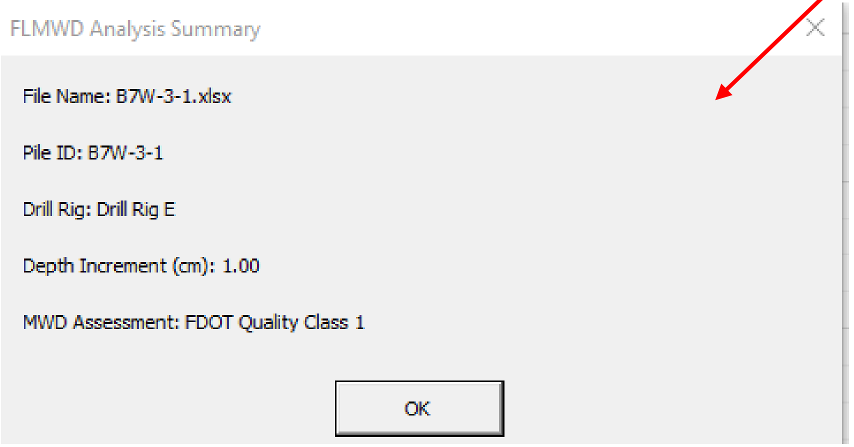




Strength Analysis

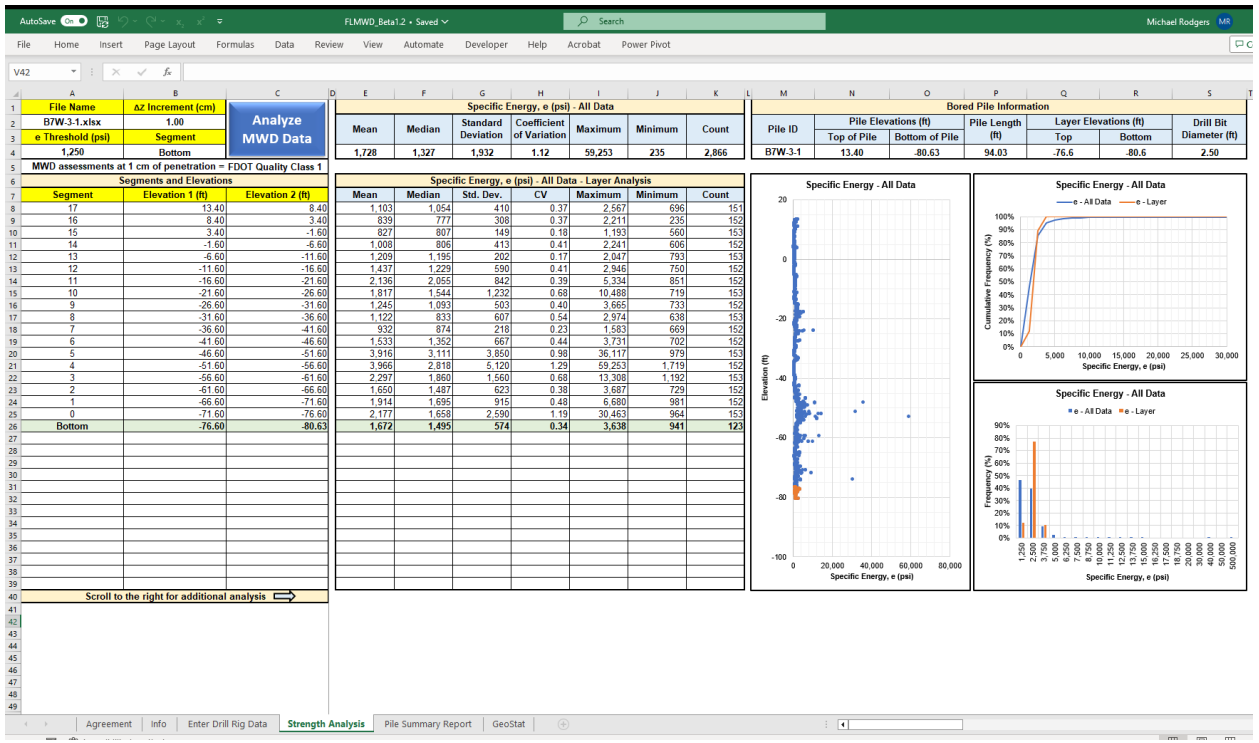






Strength Analysis – Specific Energy Threshold

All Specific Energy Data



File Name	ΔZ Increment (cm)
B7W-3-1.xlsx	1.00
e Threshold (psi)	Segment
1,250	Bottom

Analyze MWD Data

MWD assessments at 1 cm of penetration = FDOT Quality Class 1

Segments and Elevations

Segment	Elevation 1 (ft)	Elevation 2 (ft)
17	13.40	8.40
16	8.40	3.40
15	3.40	-1.60
14	-1.60	-6.60
13	-6.60	-11.60
12	-11.60	-16.60
11	-16.60	-21.60
10	-21.60	-26.60
9	-26.60	-31.60
8	-31.60	-36.60
7	-36.60	-41.60
6	-41.60	-46.60
5	-46.60	-51.60
4	-51.60	-56.60
3	-56.60	-61.60
2	-61.60	-66.60
1	-66.60	-71.60
0	-71.60	-76.60
Bottom	-76.60	-80.63

Scroll to the right for additional analysis

Specific Energy, e (psi) - All Data

Mean	Median	Standard Deviation	Coefficient of Variation	Maximum	Minimum	Count
1,728	1,327	1,932	1.12	59,253	235	2,866

Bored Pile Information

Pile ID	Pile Elevations (ft)		Pile Length (ft)	Layer Elevations (ft)		Drill Bit Diameter (ft)
	Top of Pile	Bottom of Pile		Top	Bottom	
B7W-3-1	13.40	-80.63	94.03	-76.6	-80.6	2.50

Specific Energy, e (psi) - All Data - Layer Analysis

Mean	Median	Std. Dev.	CV	Maximum	Minimum	Count
1,103	1,054	410	0.37	2,567	696	151
839	777	308	0.37	2,211	235	152
827	807	149	0.18	1,193	560	153
1,008	806	413	0.41	2,241	606	152
1,209	1,195	202	0.17	2,047	793	153
1,437	1,229	590	0.41	2,946	750	152
2,136	2,055	842	0.39	5,334	851	152
1,817	1,544	1,232	0.68	10,488	719	153
1,245	1,093	503	0.40	3,665	733	152
1,122	833	607	0.54	2,974	638	153
932	874	218	0.23	1,583	669	152
1,533	1,352	667	0.44	3,731	702	152
3,916	3,111	3,850	0.98	36,117	979	153
3,966	2,818	5,120	1.29	59,253	1,719	152
2,297	1,860	1,560	0.68	13,308	1,192	153
1,650	1,487	623	0.38	3,687	729	152
1,914	1,695	915	0.48	6,680	981	152
2,177	1,658	2,590	1.19	30,463	964	153
1,672	1,495	574	0.34	3,638	941	123

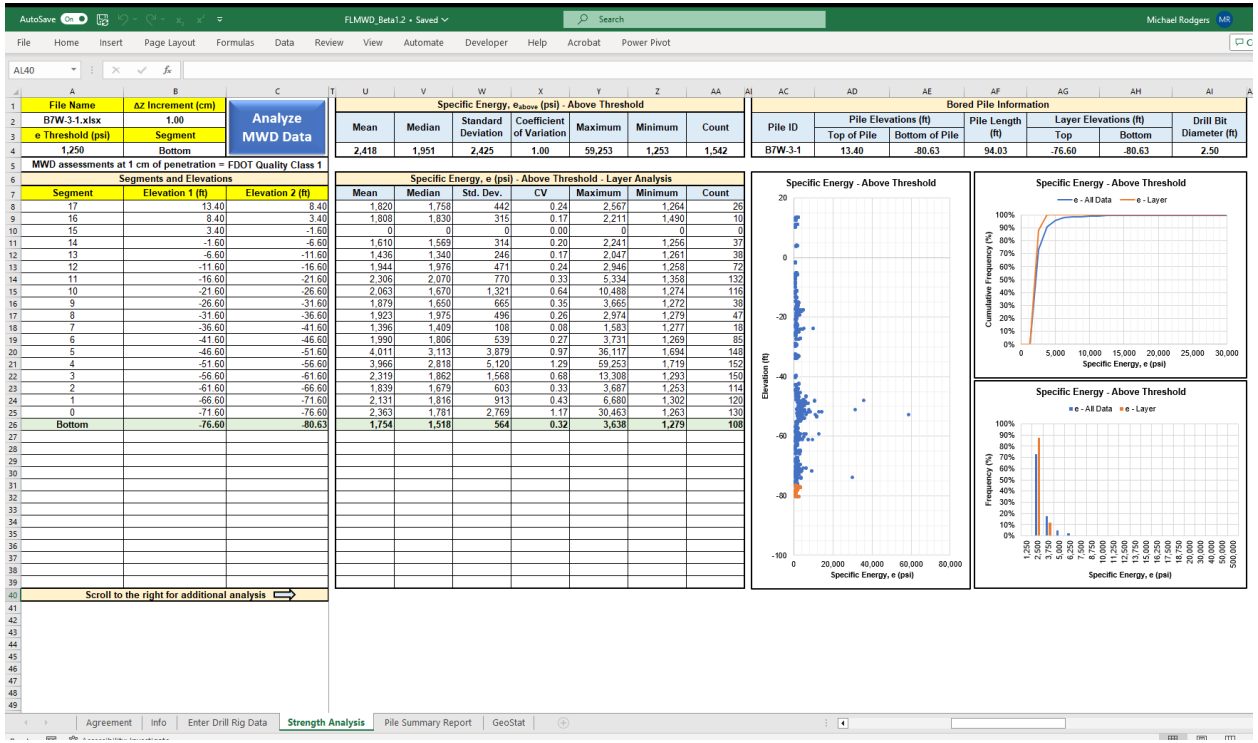
Specific Energy - All Data

Specific Energy - All Data

Specific Energy - All Data

Agreement | Info | Enter Drill Rig Data | Strength Analysis | Pile Summary Report | GeoStat

Only Specific Energy Data Above Threshold



File Name	ΔZ Increment (cm)
B7W-3-1.xlsx	1.00
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1,250	Bottom

Analyze MWD Data

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12	-11.60	-16.60
11	-16.60	-21.60
10	-21.60	-26.60
9	-26.60	-31.60
8	-31.60	-36.60
7	-36.60	-41.60
6	-41.60	-46.60
5	-46.60	-51.60
4	-51.60	-56.60
3	-56.60	-61.60
2	-61.60	-66.60
1	-66.60	-71.60
0	-71.60	-76.60
Bottom	-76.60	-80.63

Scroll to the right for additional analysis

Specific Energy, e_{above} (psi) - Above Threshold

Mean	Median	Standard Deviation	Coefficient of Variation	Maximum	Minimum	Count
2,418	1,951	2,425	1.00	59,253	1,253	1,542

Bored Pile Information

Pile ID	Pile Elevations (ft)		Pile Length (ft)	Layer Elevations (ft)		Drill Bit Diameter (ft)
	Top of Pile	Bottom of Pile		Top	Bottom	
B7W-3-1	13.40	-80.63	94.03	-76.60	-80.63	2.50

Specific Energy, e (psi) - Above Threshold - Layer Analysis

Mean	Median	Std. Dev.	CV	Maximum	Minimum	Count
1,820	1,758	442	0.24	2,567	1,264	26
1,808	1,830	315	0.17	2,211	1,490	10
0	0	0	0.00	0	0	0
1,610	1,569	314	0.20	2,241	1,256	37
1,436	1,340	246	0.17	2,047	1,261	38
1,944	1,976	471	0.24	2,946	1,258	72
2,306	2,070	770	0.33	5,334	1,358	132
2,063	1,670	1,321	0.64	10,488	1,274	116
1,879	1,650	665	0.35	3,665	1,272	38
1,923	1,975	496	0.26	2,974	1,279	47
1,396	1,409	108	0.08	1,583	1,277	18
1,990	1,806	539	0.27	3,731	1,269	85
4,011	3,113	3,879	0.97	36,117	1,694	148
3,966	2,818	5,120	1.29	59,253	1,719	152
2,319	1,862	1,568	0.68	13,308	1,293	150
1,839	1,679	603	0.33	3,687	1,253	114
2,131	1,816	913	0.43	6,680	1,302	120
2,363	1,781	2,769	1.17	30,463	1,263	130
1,754	1,518	564	0.32	3,638	1,279	108

Specific Energy - Above Threshold

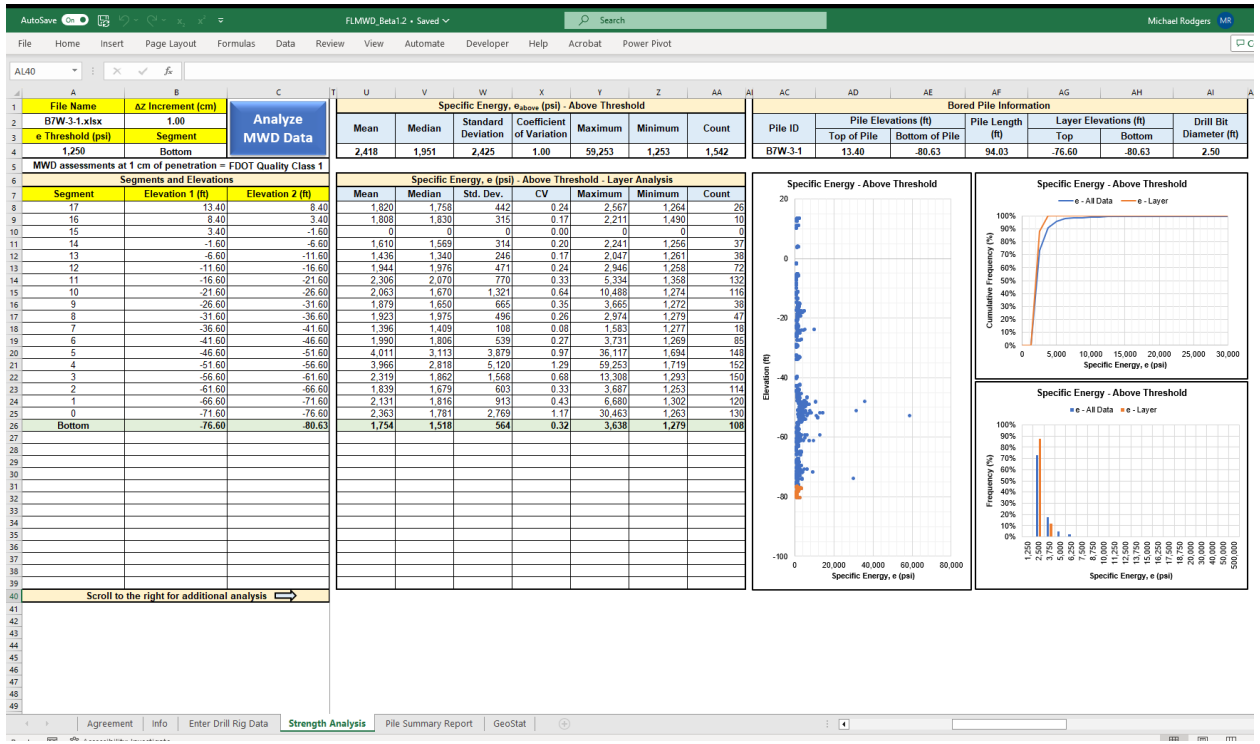
Specific Energy - Above Threshold

Specific Energy - Above Threshold

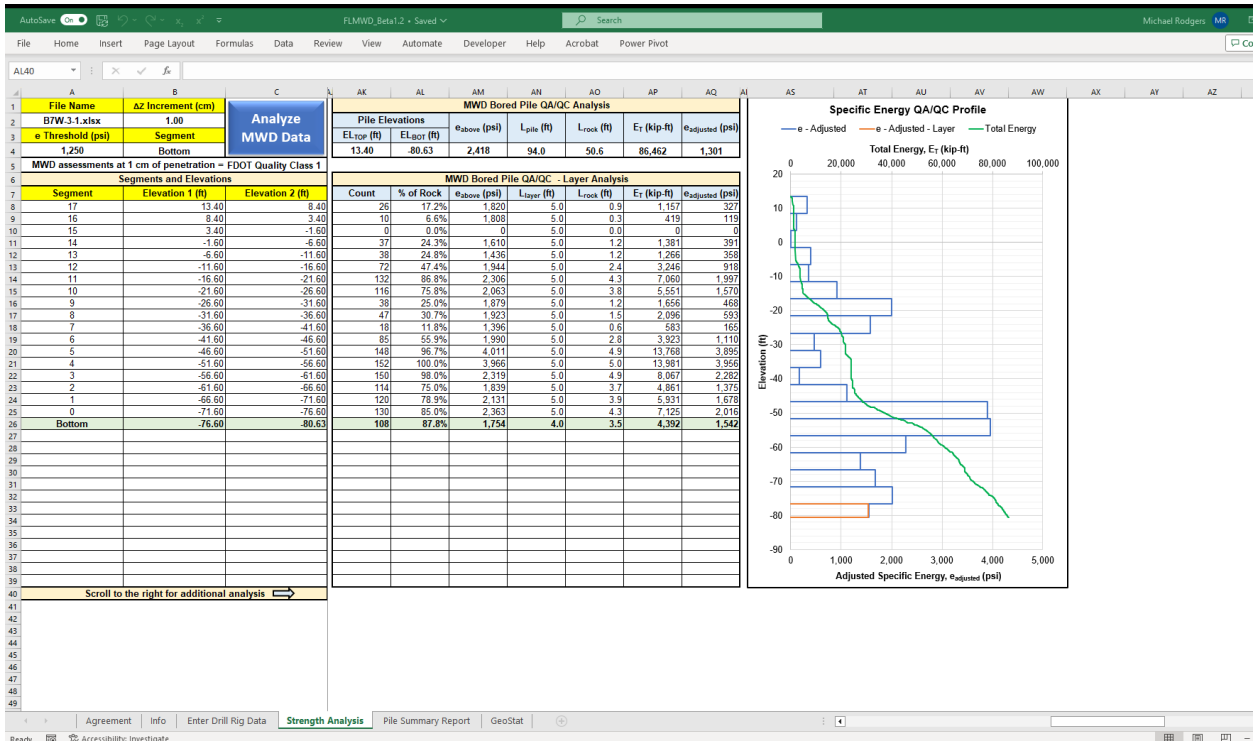
Agreement | Info | Enter Drill Rig Data | Strength Analysis | Pile Summary Report | GeoStat

Strength Analysis – Specific Energy Threshold

Only Specific Energy Data Above Threshold



Bored Pile QA/QC Analysis



Pile Summary Report

MWD Summary Report

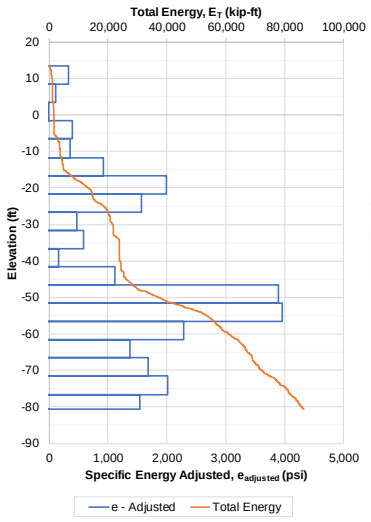
Engineer	Pile ID	Drill Rig	Drill Bit Diameter (in)
Michael Rodgers	7W-3-1	Drill Rig B	30
Project	**Location**	**Top of Pile Elevation (ft)**	**Bottom of Pile Elevation (ft)**
UF Demo	Gainesville, FL	13.40	-80.63
Station	**Offset (ft)**	**Depth Increment Analyzed (cm)**	**MWD Assessment**
100+00.01	10.00	1.00	FDOT Quality Class 1

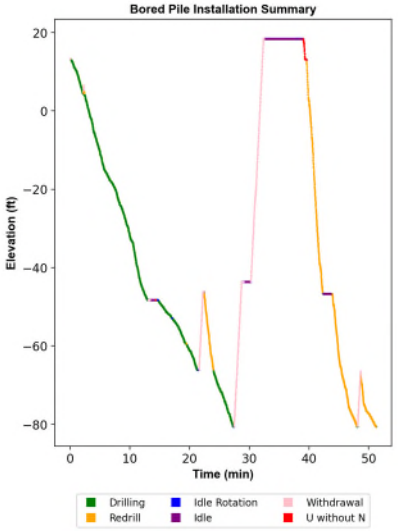
Specific Energy, e (psi) - All Data	
Mean	1,728
Median	1,327
Standard Deviation	1,932
Coefficient of Variation (CV)	1.12
Maximum	59,253
Minimum	235
Number of Data Points	2,866

ACIP Pile QA/QC - Rock Socket Assessment	
Pile Length (ft)	94.03
Total Rock Socket Length (ft)	50.59
Pile Pecentage of Rock (%)	54%
Specific Energy Threshold (psi)	1,250
Specific Energy, e_{above} (psi)	2,418
Specific Energy, $e_{adjusted}$ (psi)	1,301
Total Energy, E_T (kip-ft)	86,469

Specific Energy, e_{above} (psi) - Above Threshold	
Mean	2,418
Median	1,951
Standard Deviation	2,425
Coefficient of Variation (CV)	1.00
Maximum	59,253
Minimum	1,253
Number of Data Points	1,542

Bored Pile Installation Summary - Time (min)	
Drilling	23.33
Redrill	11.43
Idle Rotation	1.55
Idle	9.10
Withdraw	5.33
Penetration without Rotation	0.52
Total	51.27





Notes:

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Date of Analysis: 8/12/2024

Create PDF

MWD Summary Report PDF Address

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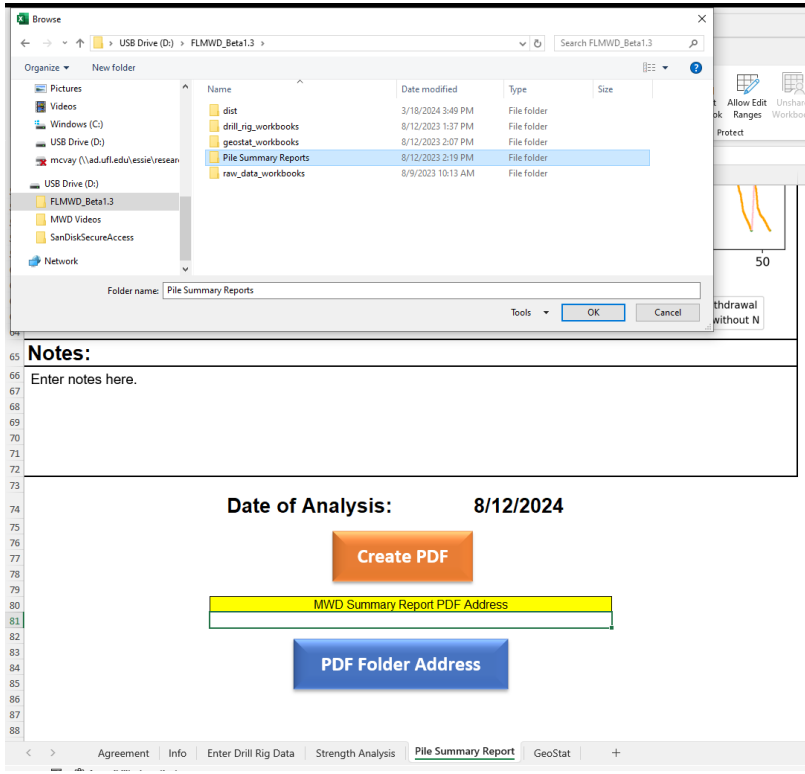
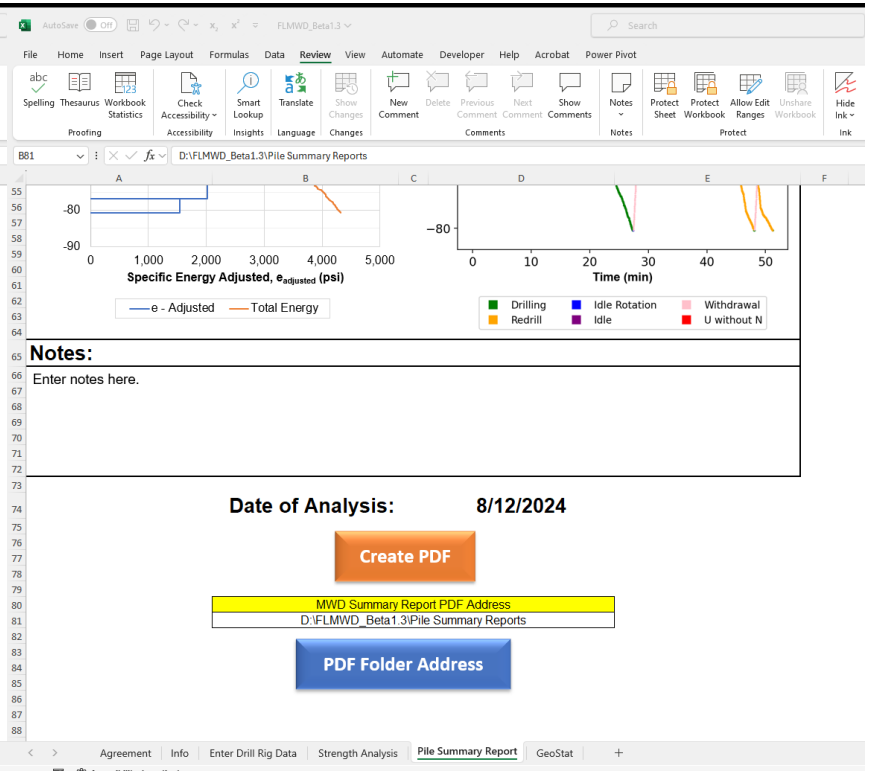
PDF Folder Address





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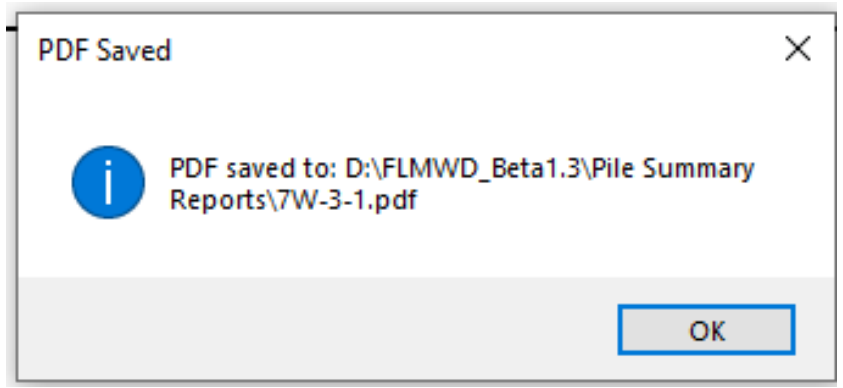

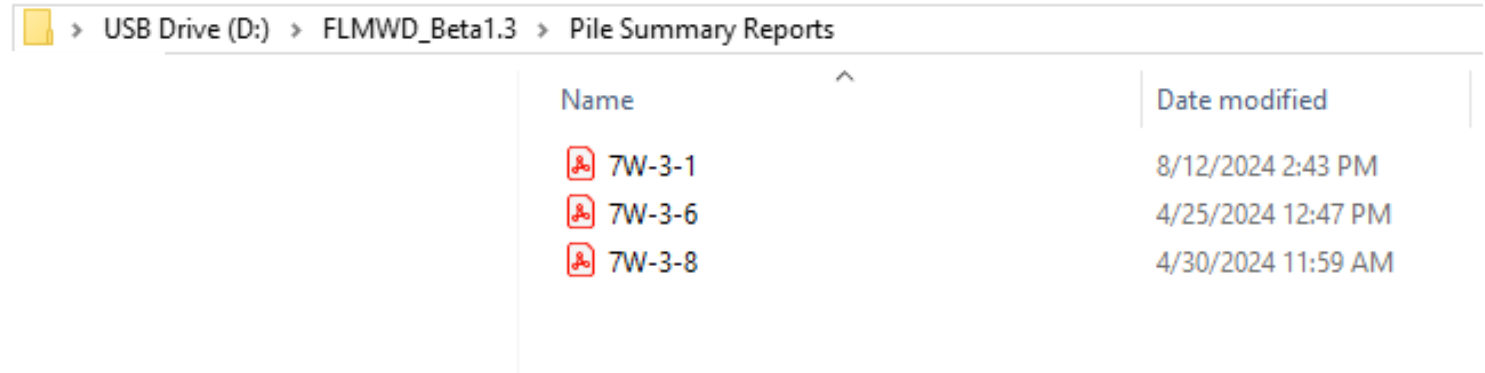

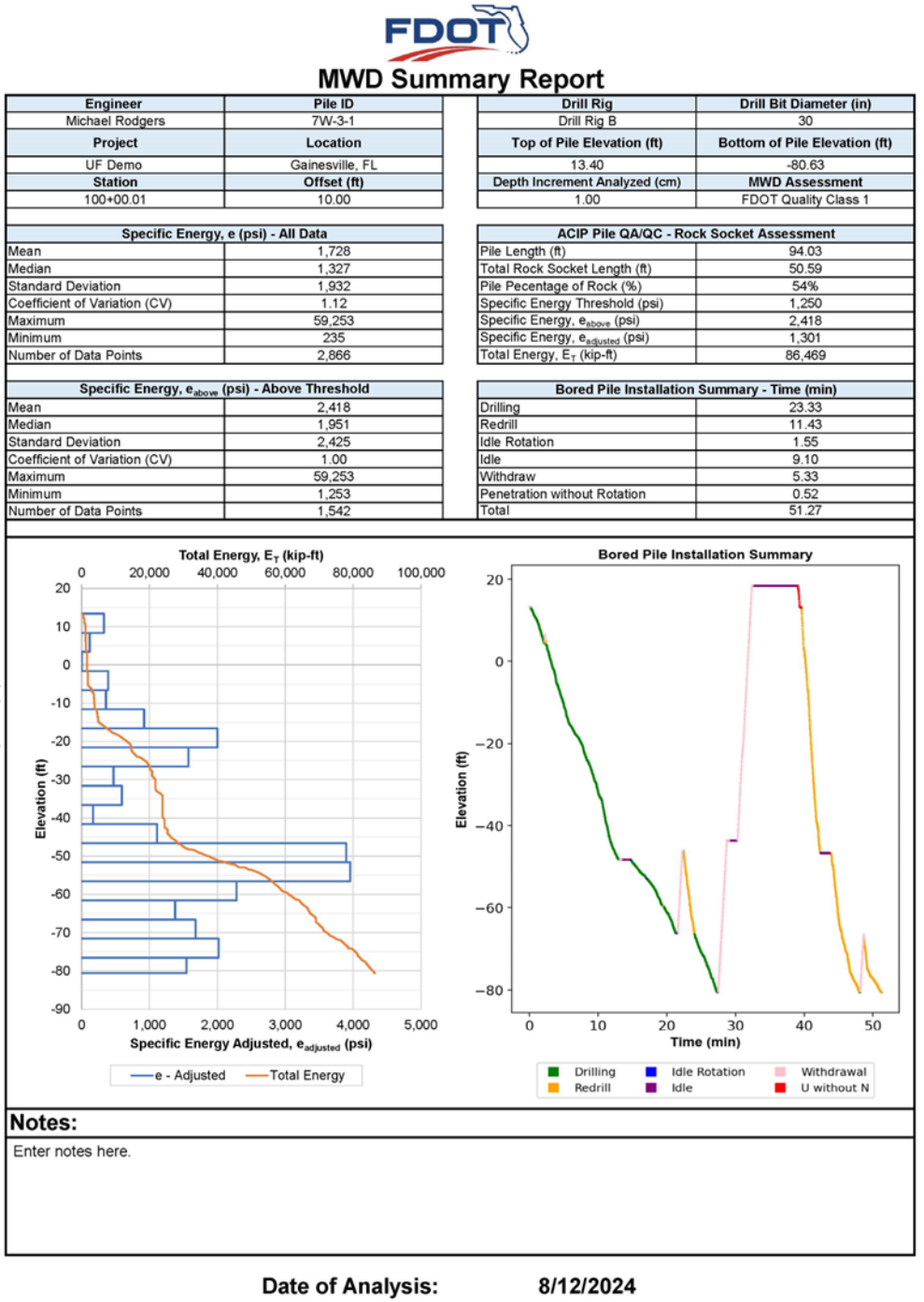

FDOT

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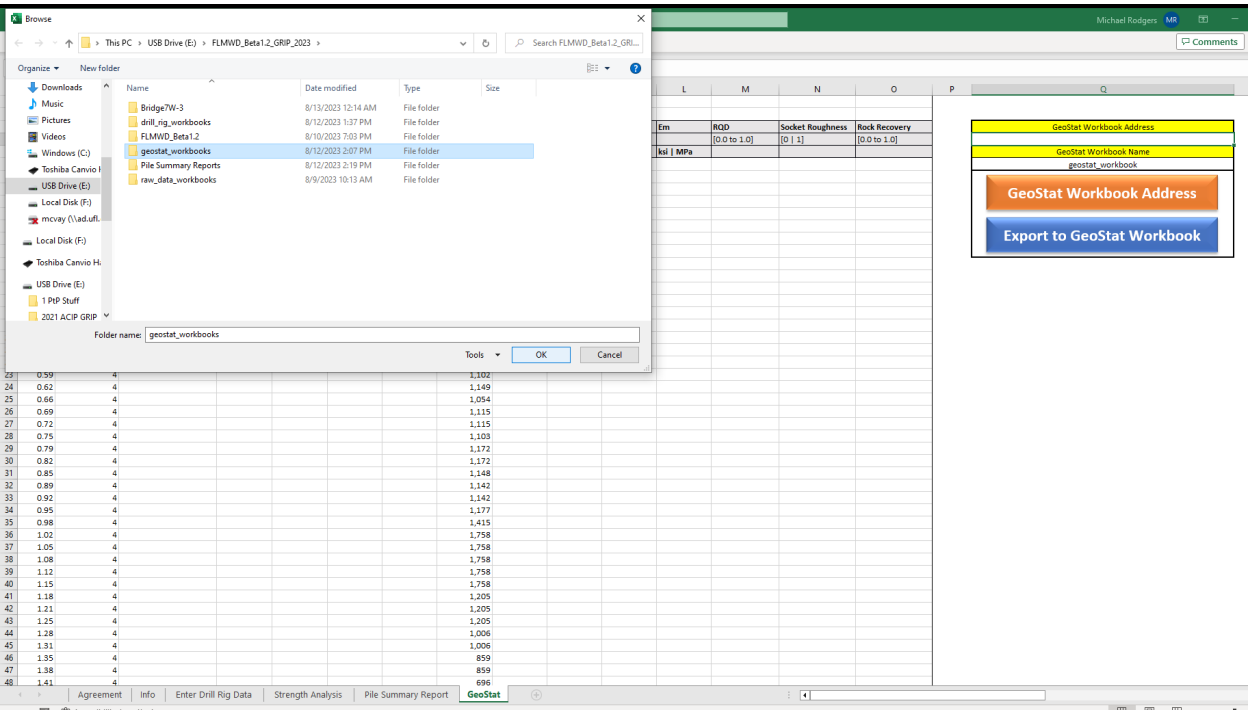
Enter notes here.

Date of Analysis: **8/12/2024**

GeoStat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Search FLMWD_Beta1.2_GRI...
Organize
New folder
Downloads
Music
Pictures
Videos
Windows (C:)
Toshiba Canvio
USB Drive (E:)
Local Disk (F:)
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Local Disk (F:)
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Size
Bridge7W-3 8/13/2023 12:14 AM File folder
drill_rig_workbooks 8/12/2023 1:37 PM File folder
FLMWD_Beta1.2 8/10/2023 7:03 PM File folder
geostat_workbooks 8/12/2023 2:07 PM File folder
Pile Summary Reports 8/12/2023 2:19 PM File folder
raw_data_workbooks 8/9/2023 10:13 AM File folder
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Tools
OK
Cancel
Michael Rodgers
Comments
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Pile Summary Report
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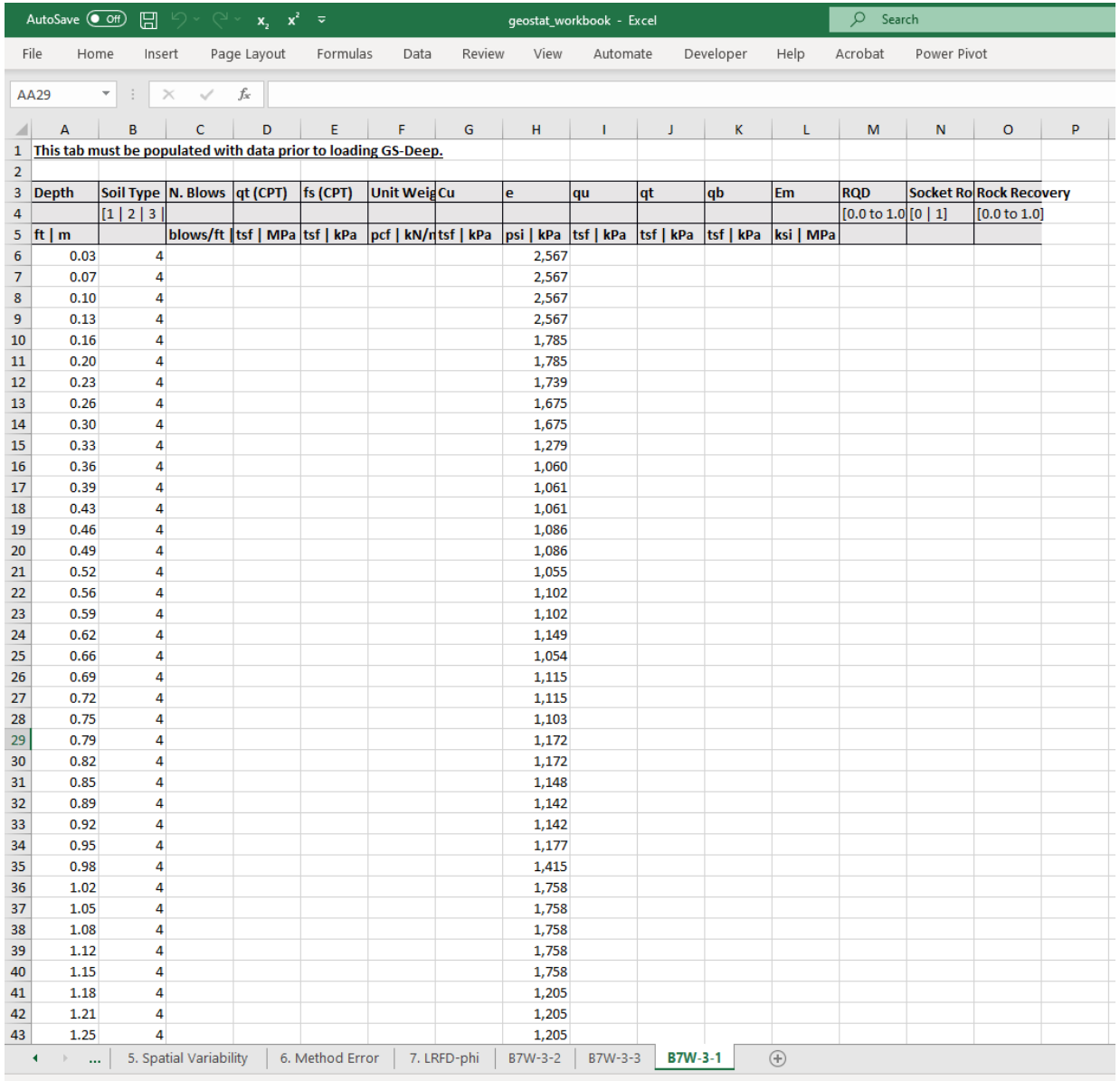
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geostat_workbook - Excel
Search
File Home Insert Page Layout Formulas Data Review View Automate Developer Help Acrobat Power Pivot
AA29
This tab must be populated with data prior to loading GS-Deep.
Depth | Soil Type | N. Blows | qt (CPT) | fs (CPT) | Unit Weig | Cu | e | qu | qt | qb | Em | RQD | Socket Ro | Rock Recovery
[1 | 2 | 3 | [0.0 to 1.0 | [0 | 1] | [0.0 to 1.0]
ft | m | blows/ft | tsf | MPa | tsf | kPa | pcf | kN/m | tsf | kPa | psi | kPa | tsf | kPa | tsf | kPa | tsf | kPa | ksi | MPa
0.03 4 2,567
0.07 4 2,567
0.10 4 2,567
0.13 4 2,567
0.16 4 1,785
0.20 4 1,785
0.23 4 1,739
0.26 4 1,675
0.30 4 1,675
0.33 4 1,279
0.36 4 1,060
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0.82 4 1,172
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0.92 4 1,142
0.95 4 1,177
0.98 4 1,415
1.02 4 1,758
1.05 4 1,758
1.08 4 1,758
1.12 4 1,758
1.15 4 1,758
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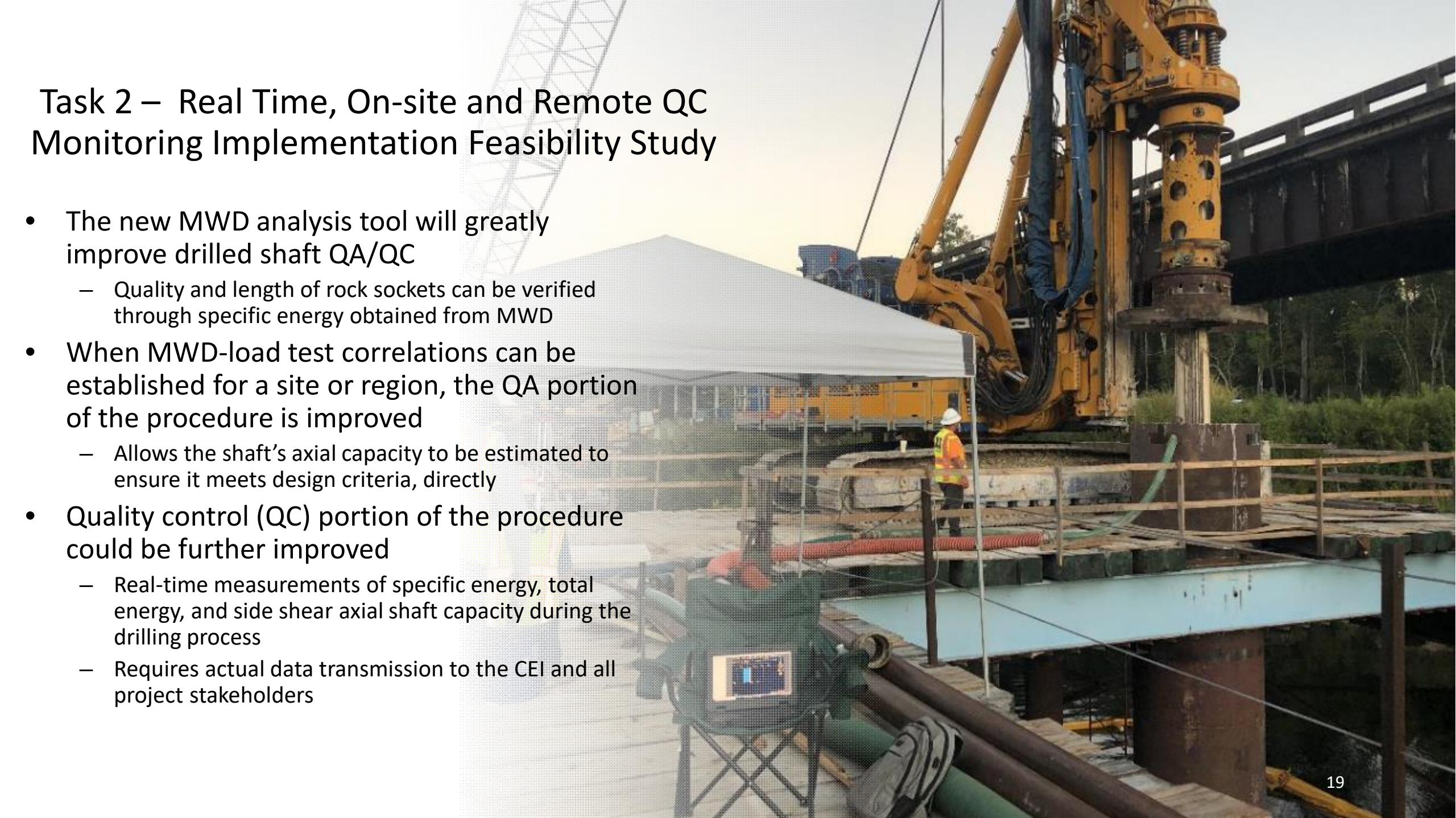
1.25 4 1,205
5. Spatial Variability
6. Method Error
7. LRFD-phi
B7W-3-2
B7W-3-3
B7W-3-1

Task 2 – Real Time, On-site and Remote QC Monitoring Implementation Feasibility Study

- The new MWD analysis tool will greatly improve drilled shaft QA/QC
  - Quality and length of rock sockets can be verified through specific energy obtained from MWD
- When MWD-load test correlations can be established for a site or region, the QA portion of the procedure is improved
  - Allows the shaft's axial capacity to be estimated to ensure it meets design criteria, directly
- Quality control (QC) portion of the procedure could be further improved
  - Real-time measurements of specific energy, total energy, and side shear axial shaft capacity during the drilling process
  - Requires actual data transmission to the CEI and all project stakeholders



Task 2 – Real Time, On-site and Remote QC Monitoring Implementation Feasibility Study

- Can currently view drilling parameters live
- Need to develop a robust method that can transmit MWD data that is applicable to all monitoring systems
  - Likely through CAN bus integration
  - SBC module can transmit actual data on-site and to remote locations via CAN and Modem hats added in
- Method demonstrated using technology already being placed on rigs

On-site and Remote Monitoring Demonstration

- **Demonstration Overview**
  - Used an SBC with web broadcast and an instrumented drill rod (BED31-977-03)
  - Custom sensor provides real-time torque, crowd, and 3-axis vibration data integrated into Jean Lutz DIALOG DAQ system
- **Custom Programming**
  - Developed SBC programming to only stream 3-axis accelerometer data
    - 4 parameters per axis, 12 total
  - 1 Hz average sampling, replicating FDOT MWD bored pile QA/QC requirements
- **Data Simulation & Storage Insight**
  - Streamed 12 parameters from 3-axis accelerometer to simulate typical FDOT MWD data stream
  - Data used to assess storage requirements for current FDOT MWD applications

Typical FDOT Bored Pile Data Stream

	A	B	C	D	E	F	G	H	I	J	K
1	Time	Duration (min)	Gear Box RPM	Penetration Rate (ft/min)	Penetration Rate (min/ft	Depth (ft)	Gear Box Pres	Torque (ft-lbs)	Crowd Pressur	Thrust (lbs)	
2	6/4/2020 10:16:38 AM	0	-79.39	-49.8359596	3.048	0	551.8684485	0	210.1596273	3258.31	
3	6/4/2020 10:16:39 AM	0.02	-79.66	-50.4921276	3.048	0	519.5250414	0	218.2817385	3384.24	
4	6/4/2020 10:16:40 AM	0.03	-79.75	-50.524936	3.048	0	448.166493	0	221.0374548	3426.96	
5	6/4/2020 10:16:41 AM	0.05	-79.8	-50.524936	3.048	0	537.6547539	0	217.8466254	3377.49	
6	6/4/2020 10:16:42 AM	0.07	-31.19	-25.262468	3.048	0	559.9905597	0	288.625023	4474.84	
7	6/4/2020 10:16:43 AM	0.08	19.49	0.0984252	10.16	0.0328084	504.8762337	0	209.7245142	3251.57	
8	6/4/2020 10:16:44 AM	0.1	19.62	0.4265092	2.344615385	0.0328084	520.685343	0	219.2970024	3399.98	
9	6/4/2020 10:16:45 AM	0.12	19.58	0.4593176	2.177142857	0.0328084	545.4867897	0	240.762582	3732.78	
10	6/4/2020 10:16:46 AM	0.13	19.54	0.984252	1.016	0.1312336	603.2117943	0	231.4801692	3588.87	

MWD Components and Simulated Data Stream Display

The SBC Code

- With the live MWD data now in place, the researchers then developed programming on the SBC to send the live data
  - External computer that mimicked onsite monitoring by the CEI
  - To the cloud to mimic remote monitoring by stakeholders involved in the project
    - Google Cloud Service, GCS
- Key Functions
  - Collect vibration data from a sensor node via a wireless base station
  - Provide visual display from SBC to simulate DAQ module display
  - Log the data into a local temporary CSV file
  - Periodically upload the data to the cloud (GCS)
  - Stream the data to a connected client (external computer) using a web socket server

SBC Main Components and Functions

- **CSV File Management**
  - Initialize a CSV file (tempdata.csv) with proper headers
  - Dynamically append new rows of sensor data to the file while ensuring headers remain consistent
- **Data Parsing and Aggregation**
  - Parse data (data packet): Extract channel data from a sensor data packet
  - Append to CSV (timestamp, channel values): Write timestamped, aggregated channel data to the CSV file
- **WebSocket Server**
  - Implement a WebSocket server that an external computer can connect to
  - Historical Data: In case of a disconnection, the system reads unsent data from the temporary CSV file and sends it to the client once connection is reestablished
  - Real-Time Data: Send live sensor data to the client after sending any historical data
- **Google Cloud Service (GCS) Configuration**
  - Authentication: Uses a service account JSON key to authenticate to GCS
  - Interaction: Upload the CSV file to a specified GCS bucket every 10 seconds
- **Periodic Updates**
  - Process incoming sensor data sweeps from the base station
  - Update GUI labels on SBC interface with the latest data
  - Scan temporary CSV file for prior entries so duplicate data is avoided
  - Log only new data to the CSV file and trigger sending data via cloud and web socket

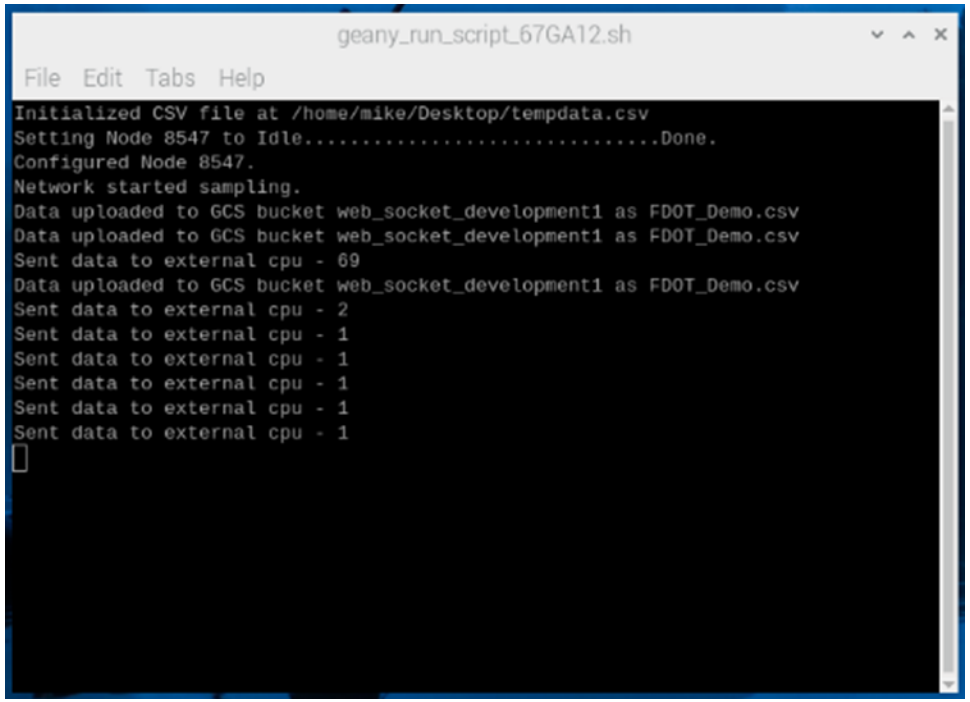
External Computer Code

- In addition to the SBC, programming was also required on the external computer side to connect with the SBC web socket server to receive and log the data
- Two data storage formats were investigated:
  - USB hard drive
  - Cloud-based drive (OneDrive)
  - This was done to determine the best mechanism to interact with the newly developed MWD bored pile analysis tool
- Key Functions
  - WebSocket Communication: Connect to the SBC web socket server to receive data
  - Data Logging: Log historical and real-time data into two text files: hard drive (USB) and a cloud-based drive (OneDrive)
  - Duplicate Prevention: Ensure no duplicate data are written using a persistence mechanism
  - Real-Time Monitoring: Open a PowerShell session to monitor data in a real-time feed

Workflow Interaction Between SBC and External Computer

- **SBC**
  - Collect sensor data and log it to a local CSV file
  - Periodically upload the data to the cloud
    - Every 10 seconds during trials
  - Stream historical and real-time data through a web socket server
  - Provide informational messages based on connection status and data sent
- **External Computer**
  - Connect to the SBC web socket server
  - Collect historical data (unsent data) first, followed by real-time data
  - Log the received data into two text file locations:
    - Hard drive (USB)
    - Cloud-based drive (OneDrive)
  - Monitor data using PowerShell for real-time feed
  - Provide informational messages based on connection status and data received

SBC Terminal Messages Sent



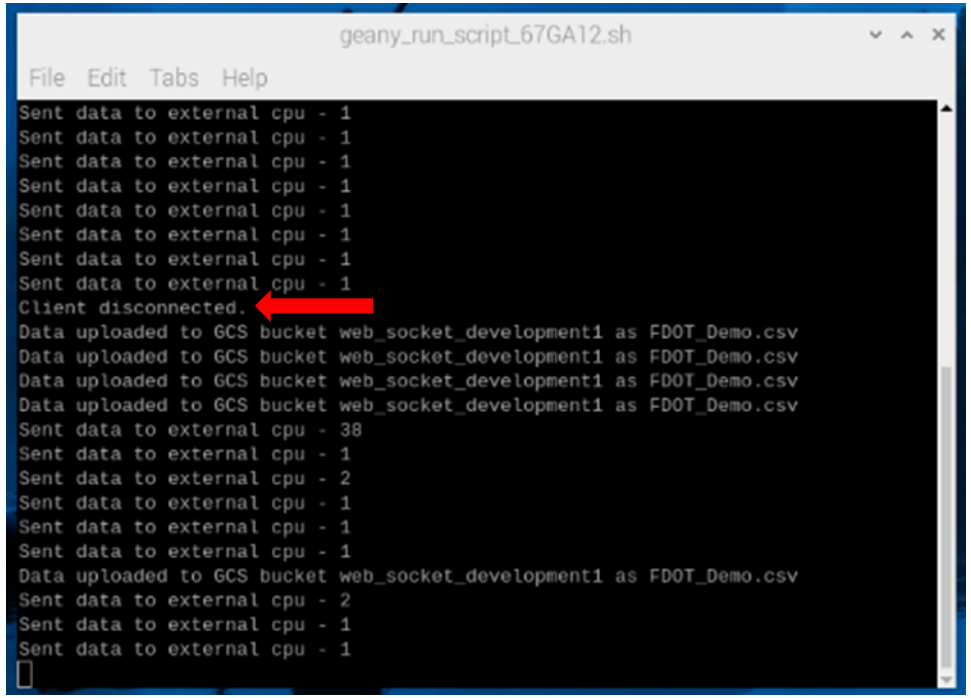
External Computer Messages Received

```
File C:\Users\micha\OneDrive\Documents\FDOT_Demo.txt is ready with headers.
Persisted timestamps reset for new file creation.
File D:\Sensor Data From Pi\FDOT_Demo.txt is ready with headers.
Persisted timestamps reset for new file creation.
PowerShell tailing started in a new window.
Connected to WebSocket server.
Received data from SBC - 69
Received data from SBC - 2
Received data from SBC - 1
Received data from SBC - 1
Received data from SBC - 1
Received data from SBC - 1
Received data from SBC - 1
```

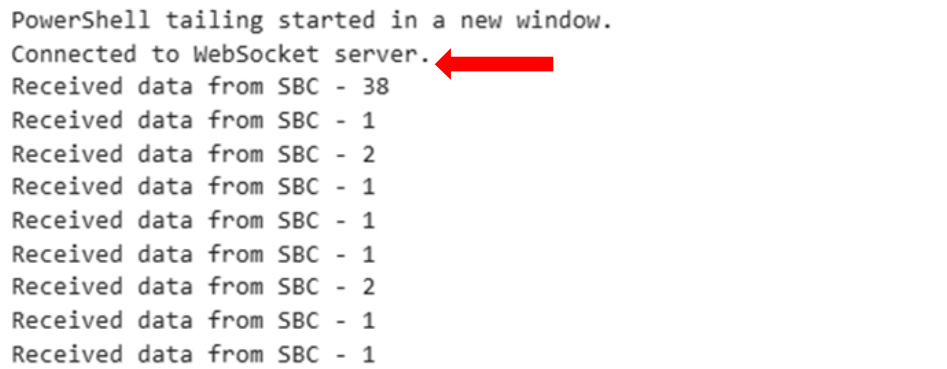
Simulate Client Disconnect

- SBC Connection Loss Handling
  - SBC detects when external computer (client) disconnects
  - Historic data is stored while the connection is lost
- Reconnection Process
  - Once client is reconnected, SBC sends stored historic data first
  - Real-time data transmission resumes
- Data Integrity
  - Logs confirm no data loss during disconnection and reconnection
  - 48 data packets sent, 48 data packets received after reconnection
  - Data always sent to the cloud

SBC Terminal Messages Sent

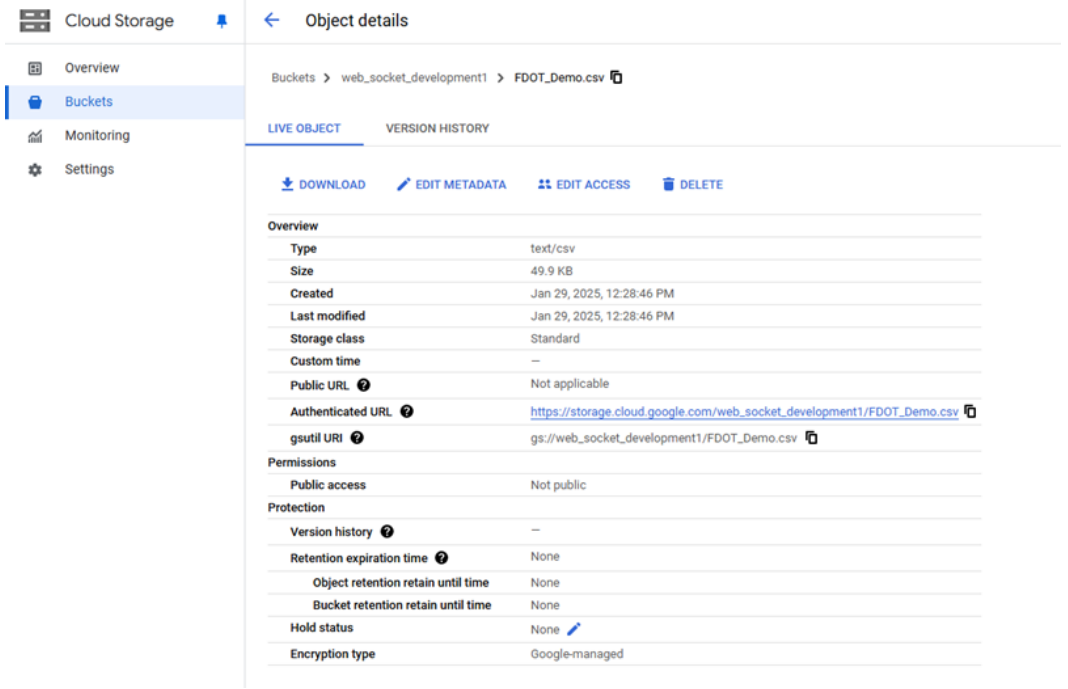


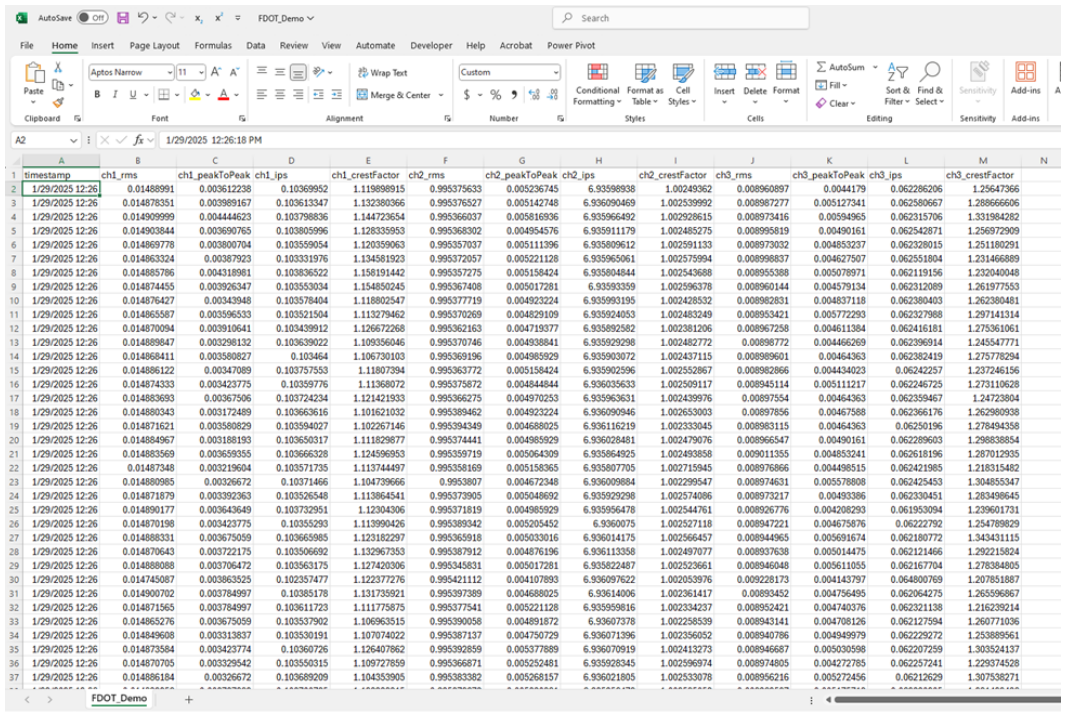
External Computer Messages Received



Remote Monitoring

- Cloud Data Broadcasting
  - SBC uploads data to cloud every 10 seconds
  - Stored in GCS bucket
- Streamlined FDOT Analysis
  - Future separate buckets for each MWD project
  - Direct upload eliminates manual downloads/emails
- Real-Time Monitoring
  - CEI can flag issues during installation for FDOT review
  - FDOT makes informed decisions from remote locations
- Data Access and Security
  - Data downloadable in CSV format compatible with MWD analysis tool
  - Secure access via JSON key, encryption by GCS or similar
- Data Health Monitoring
  - Server/client error rate tracking
  - Confirm successful data transmission
- Future Integration
  - Insights for FDOT's MWD system specifications
  - Ensures compatibility with new MWD QC tool





Remaining Tasks

- Deliverable 1 – Establish drilled shaft MWD data reduction criteria and procedures (Task 1)
- Deliverable 2 – On-site and remote monitoring implementation feasibility study (Task 2)
- Deliverable 3 – MWD specific energy vs. drilled shaft side shear correlation (Task 3)
- Deliverable 4 – MWD correlation validation for drilled shaft QA/QC (Task 4)
- Deliverable 5a - Draft Final (Task 5)
- Deliverable 5b - Closeout Meeting (Task 5)
- Deliverable 6 - Final Report (Task 6)

Questions?