

Estimating the As-Placed Grout Volume of Auger Cast Piles

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GRIP 2024

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Auger Cast Piles

Auger cast piles are constructed using a full-length auger, providing excavation stability without using mechanical or hydrostatic support.

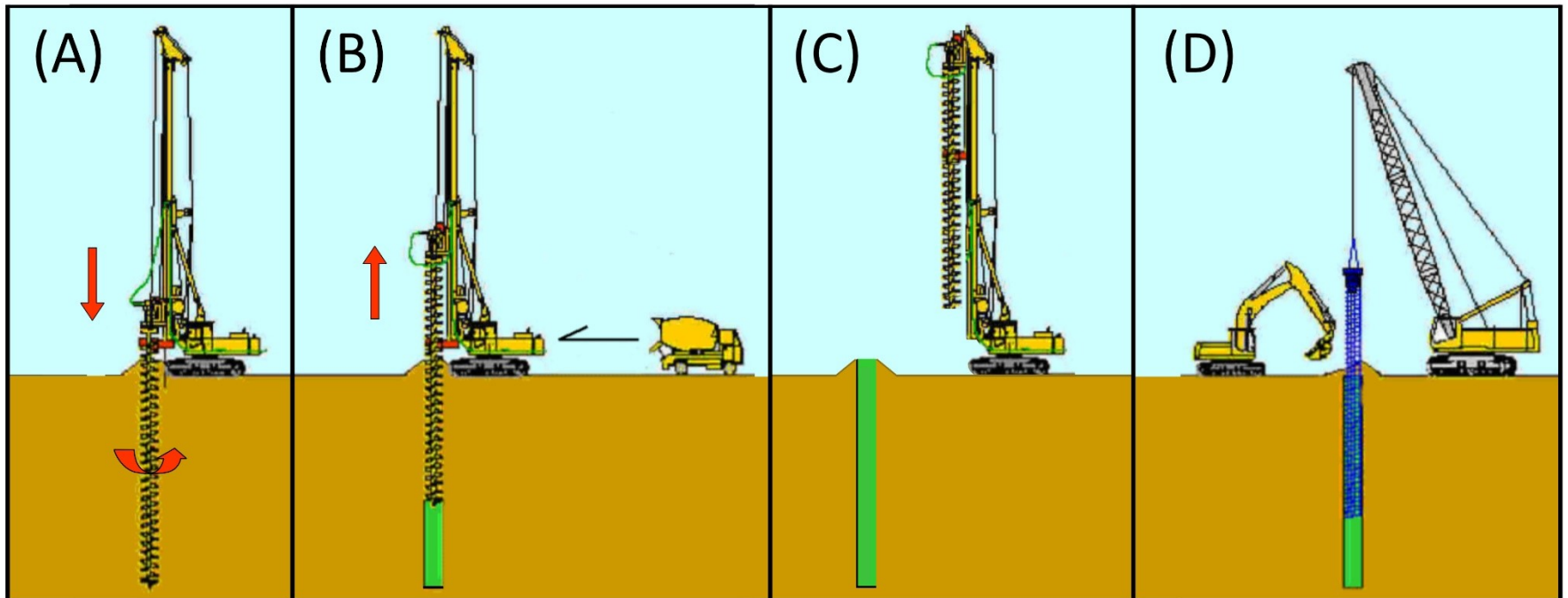
Once drilled, grout (sand, cement, water mix) is pumped through the hollow auger stem during auger extraction to create a continuously grouted column.

Image source: **(left)** Geotechnical Engineering Circular (GEC) No. 8 (2007) **(right)** FDOT



Installation Process

(A) drilling (B) grouting (C) pile grouting complete and (D) reinforcement cage placement



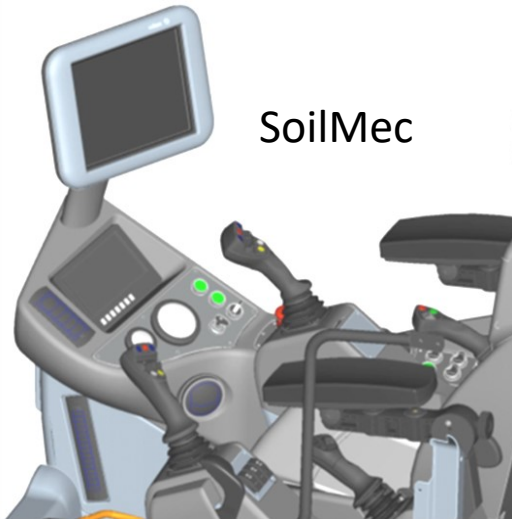
Grout Volume Monitoring

Grout volume is monitored by **(1)** a magnetic flow meter and **(2)** counting pump strokes and using pump calibration (cuft/stroke)



Image source: **(left)** ACIP Pile Installation Monitoring, Full-scale Load Testing, and Extraction program – DFI (2017) and **(right)** Geotechnical Engineering Circular (GEC) No. 8 (2007)

Automated Measuring Equipment (AME)



SoilMec

Auger depth
RPM
Crowd force/pressure
Grout flow meter
Grout pressure
Auger torque
RPM
Lift cable load
Derrick inclination

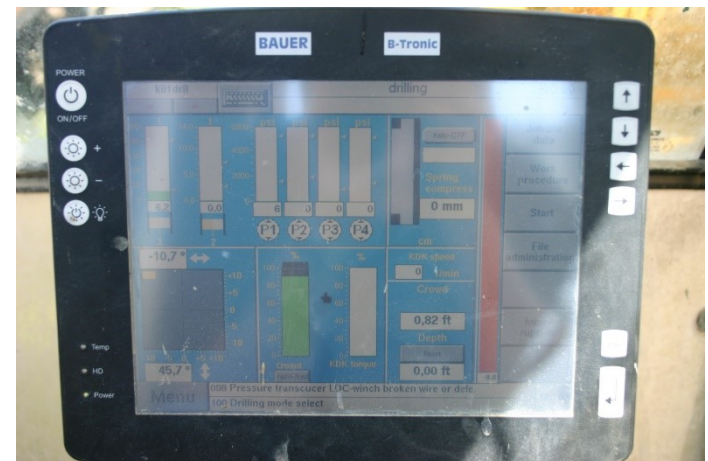


Bauer

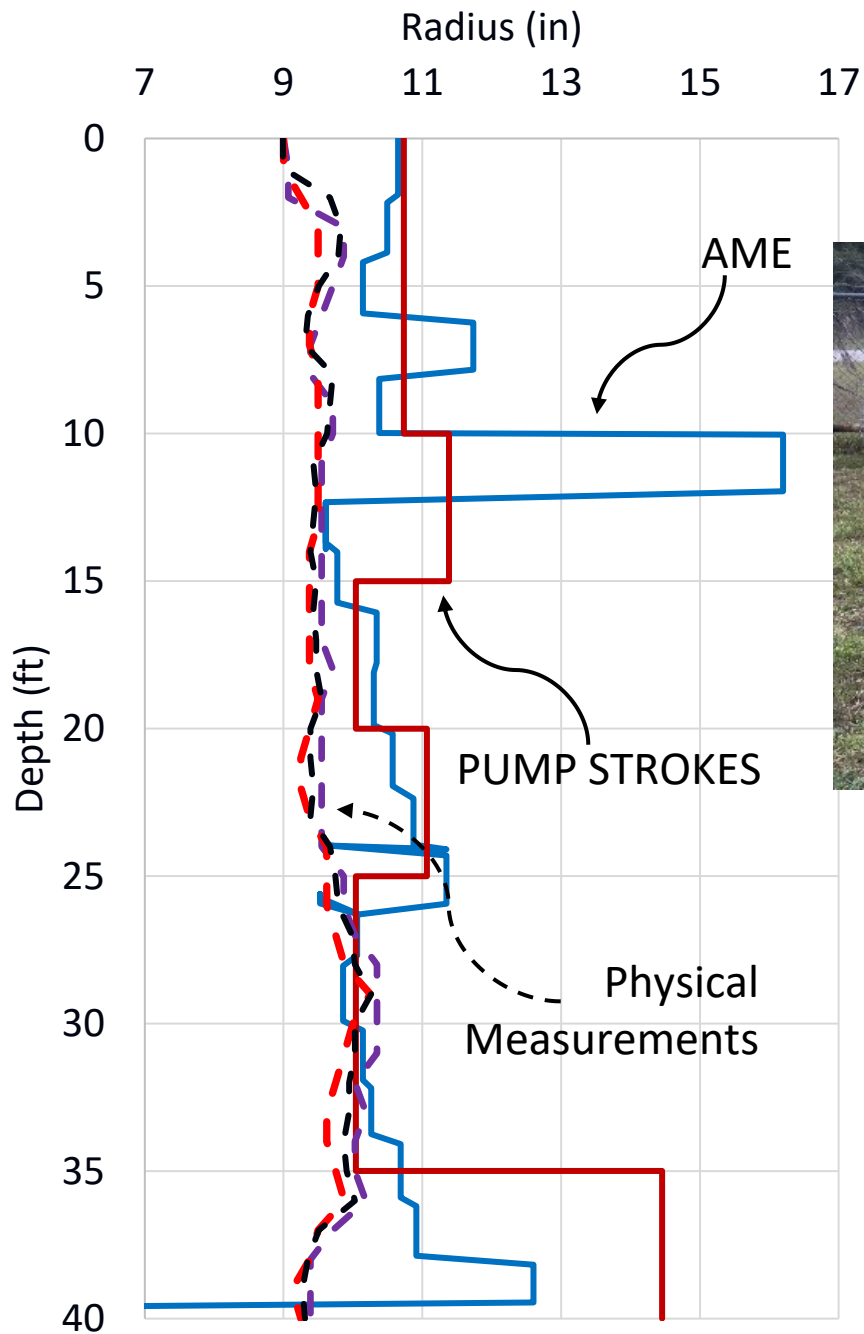


PDI

Engine temp
Oil temp
Coolant level
Oil life
Etc.



Pumped volume vs measured pile size



Problem Statement

- Despite advances in grout volume monitoring systems and increased details in field inspection logs, the as-built volume of grout in the excavation remains largely unknown.

Objectives

- To obtain field data from ACIP pile projects to better correlate the measured grout volume to the as-built pile dimensions.
- To develop a more reliable method for estimating grout volume by identifying the variables that affect pile volume other than the simplistic approaches used to date.
 - Variables are likely to include but are not limited to: soil type, construction means/methods, and types of equipment.

Work Tasks

- Task 1: Previously Collected Data
- Task 2: Collection of New Data
- Task 3: Data Analysis
- Task 4a: Draft Final Report
- Task 4b: Closeout Meeting / Presentation
- Task 5: Final Report

Grout Volume Definitions

- **Volume 1:** Priming Volume, grout volume required to prime grout pump, fill all hoses, and fill the hollow auger stem. Remember to subtract the auger stem volume when moving from a previously constructed pile.
- **Volume 2:** Initial Head Volume, grout head required by FDOT 2020 Standard Specifications for Road and Bridge Construction, Section 455-44.2. Volume equivalent to the corresponding volume of 20ft of pile length or 20% of total pile length (5ft or 10% for non-bridge foundations).
- **Volume 3:** Incremental Volume, 115% volume pumped into excavation as auger is extracted for each 5ft to ensure uniform grout distribution throughout the length of the pile. Volume 3 tracking ends at the moment of grout return.
- **Volume 4:** Finishing Volume, the grout volume pumped after grout return including a portion of finished pile volume and grout wasted at the ground surface as grout continues to be pumped as the auger is extracted after the time of grout return.

Auger cast pile volume

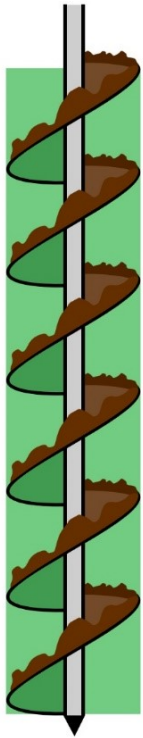
Pile Volume = Vol 2 + Vol 3 + Portion of Vol 4

- *Portion of Vol 4 = $AFF * \pi r^2 L_{return}$*
- *Pile Volume = Vol 2 + Vol 3 + $AFF * \pi r^2 L_{return}$*

where: L_{return} = return depth

AFF = Auger Fill Factor

Auger Fill Factor (AFF)



■ PORTION OF RETURN DEPTH
EXCAVATION VOLUME
ALREADY TRACKED

■ SOIL CUTTINGS

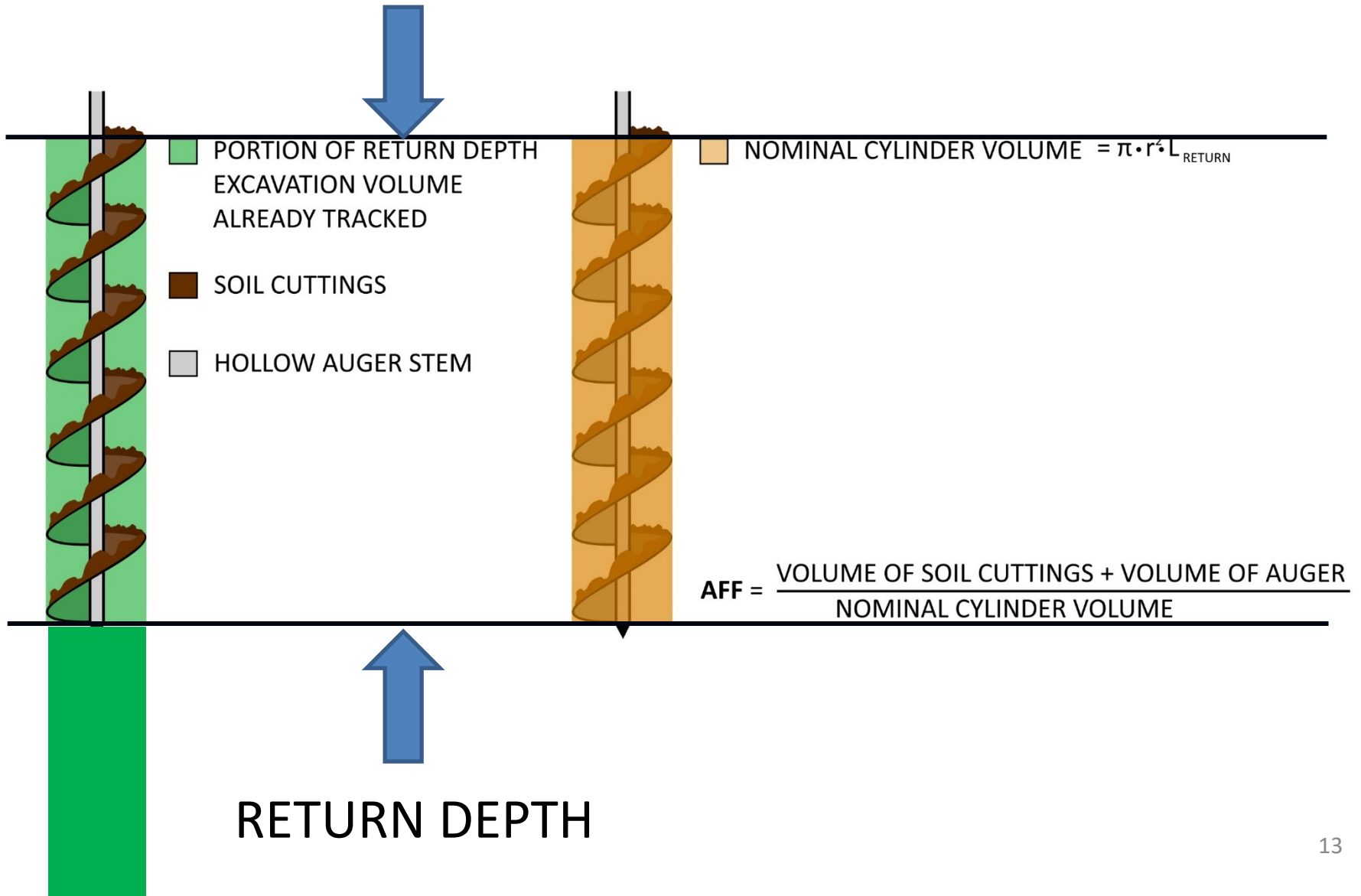
■ HOLLOW AUGER STEM



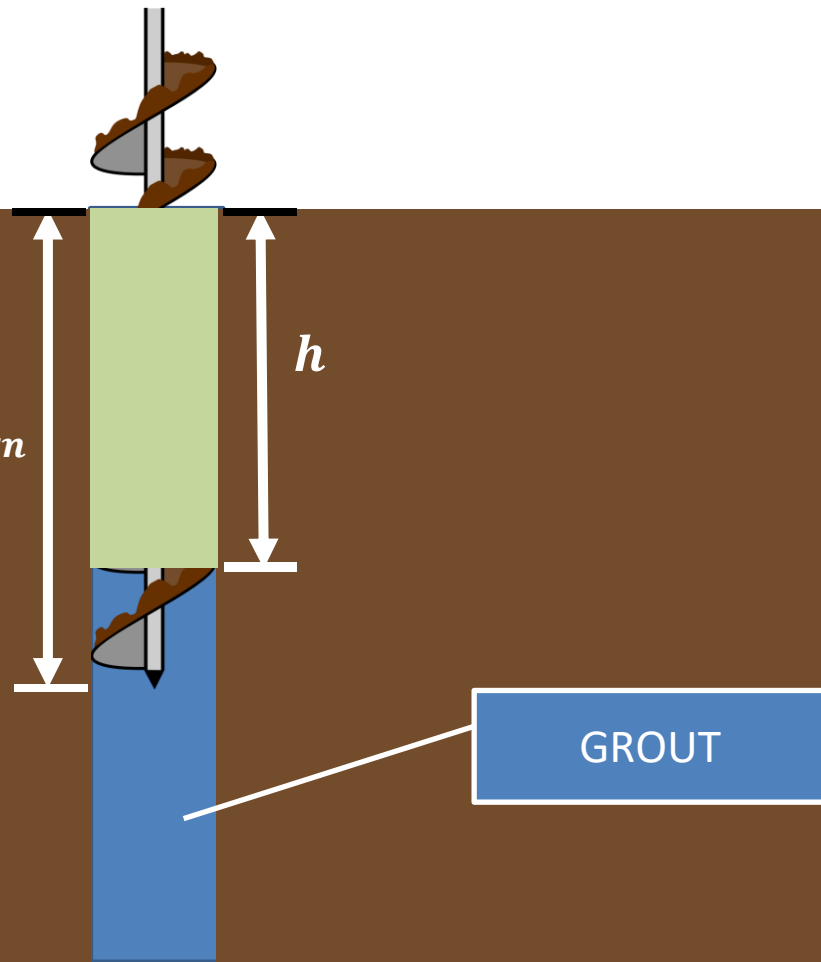
■ NOMINAL CYLINDER VOLUME = $\pi \cdot r^2 \cdot L_{\text{RETURN}}$

$$\text{AFF} = \frac{\text{VOLUME OF SOIL CUTTINGS} + \text{VOLUME OF AUGER}}{\text{NOMINAL CYLINDER VOLUME}}$$

Auger Fill Factor (AFF)



$$AFF = \frac{\text{Volume}_{\text{Auger+soil}}}{\pi r^2 L_{\text{Return}}} = \frac{\pi r^2 h}{\pi r^2 L_{\text{Return}}}$$
$$= \frac{h}{L_{\text{Return}}}$$



Types of soil adhesion



Soil cuttings adhere to auger stem



Hybrid soil cling mode



Soil cuttings sit on auger flights

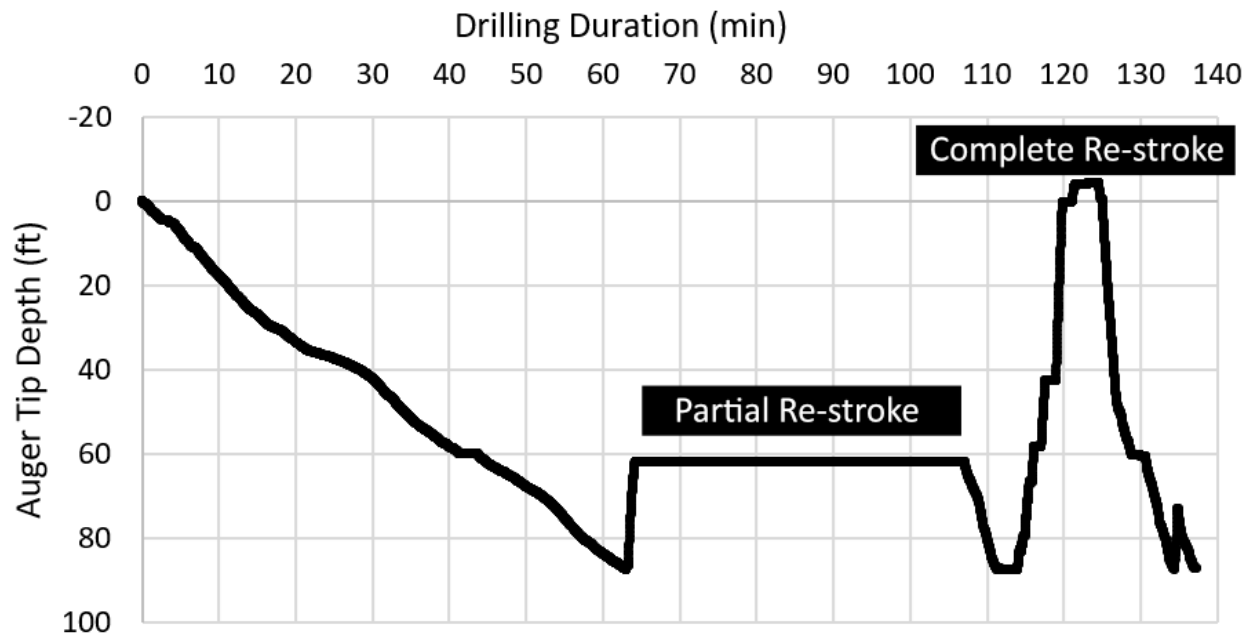
Auger cast installation data received from the I-395/SR 836/I-95 expansion in Miami, FL.



Image source: **(left & right)** FDOT & Miami-Dade Expressway Authority (MDX 2017)

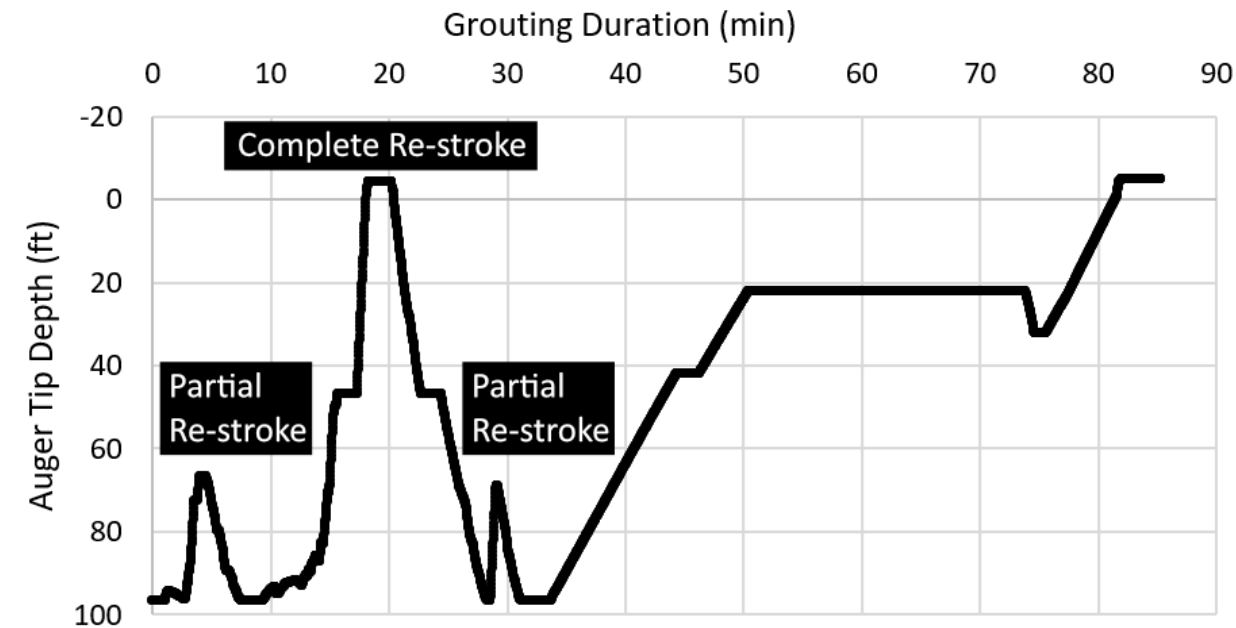
Analysis Performed

- Identification and recording of partial and complete auger re-stroking where pile excavation is left unsupported.
- Comparison of grout volumes as measured by **(1)** counting pump strokes (using corresponding cuft/stroke) and **(2)** magnetic flow meter measurements recorded by AME.
- Compare measured and predicted pile diameter

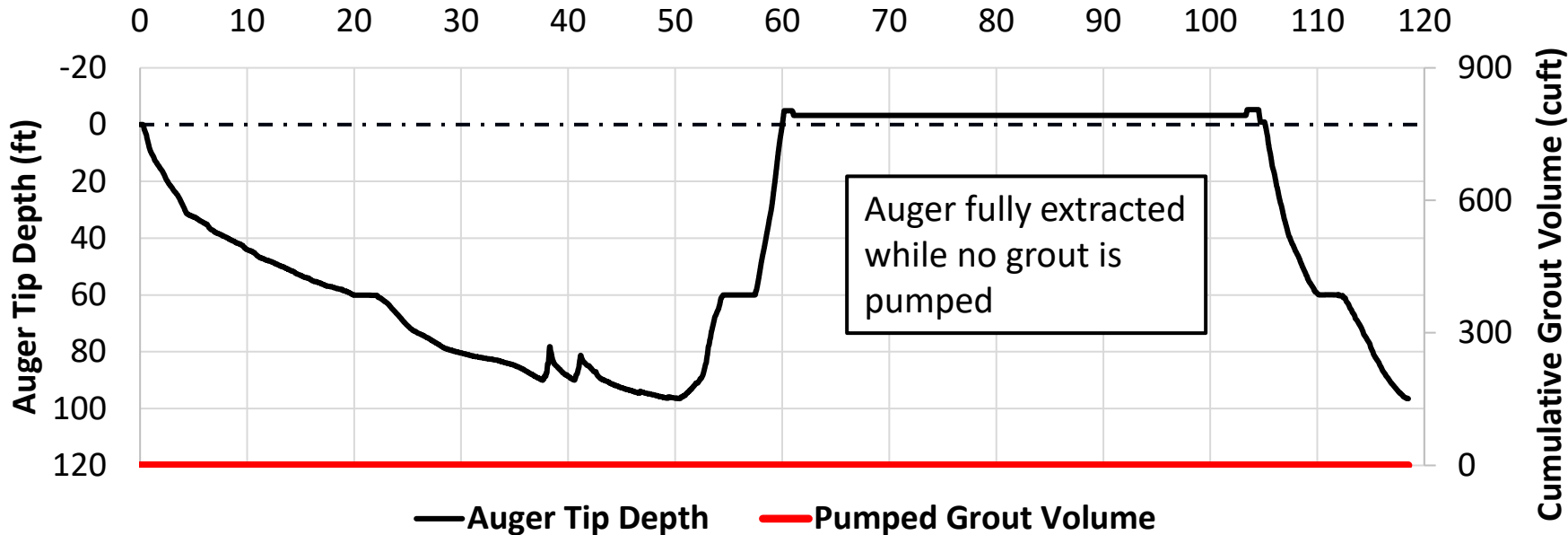


Example partial and complete re-strokes, where excavation is unsupported.

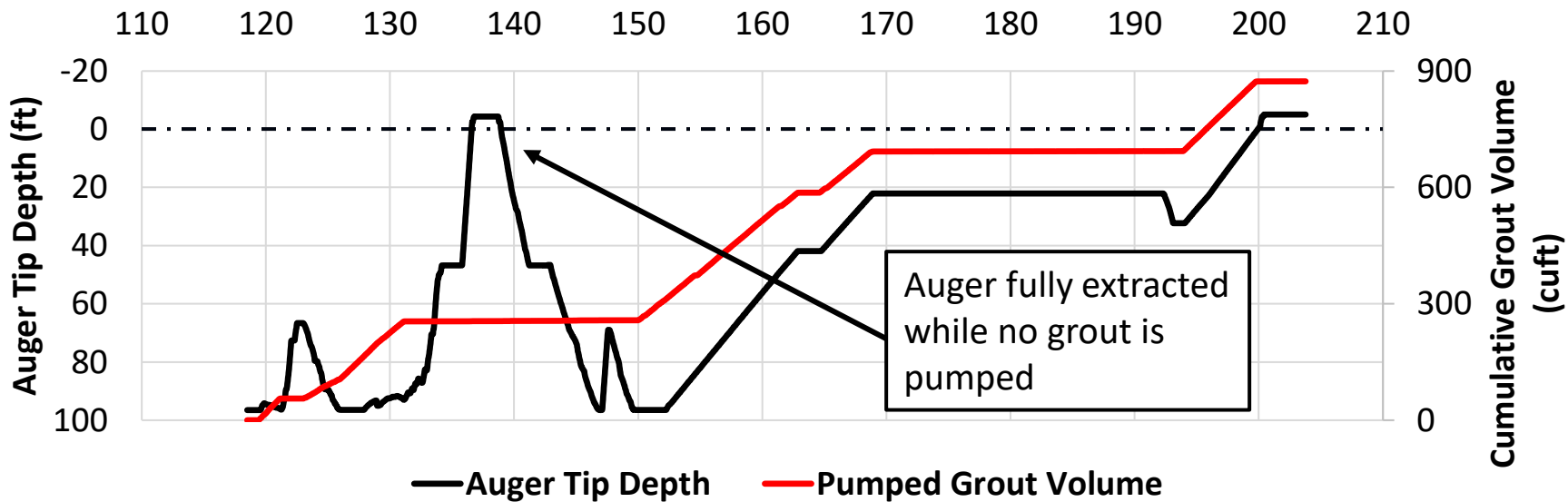
Of 386 auger cast piles analyzed, 59.6% had at least one re-stroke.



Drilling: Time (min)



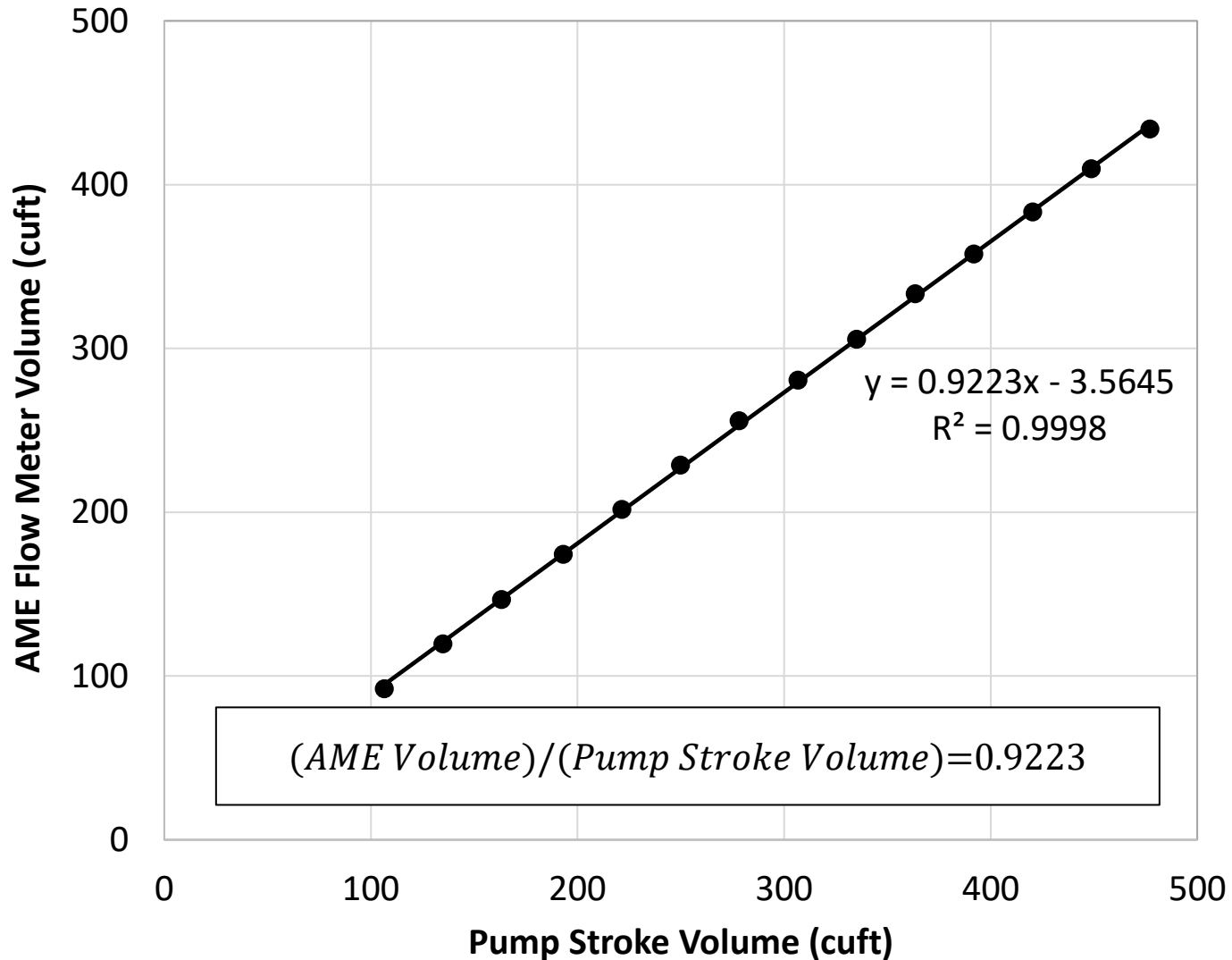
Grouting: Time (min)



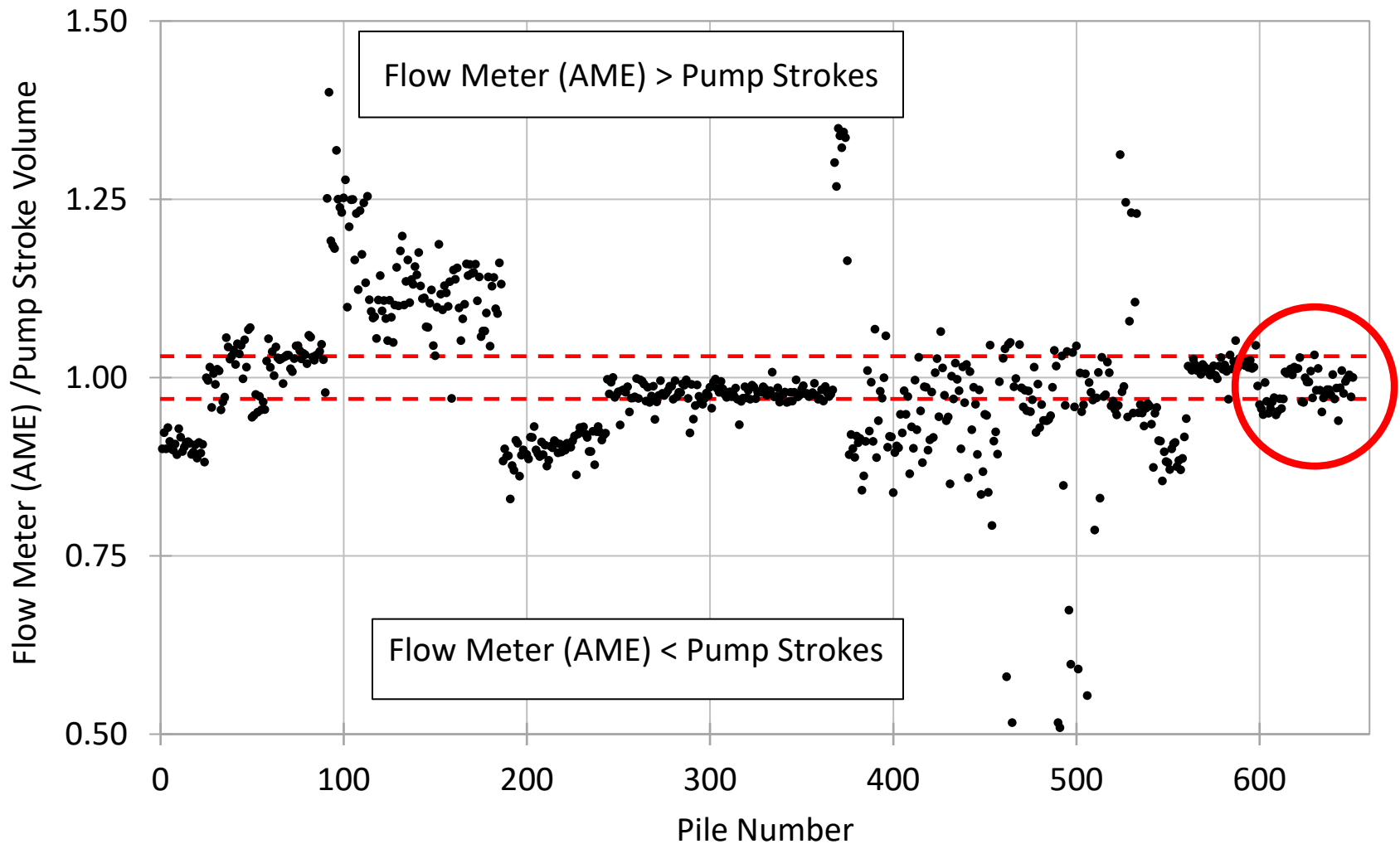
Observed frequency of re-stroking

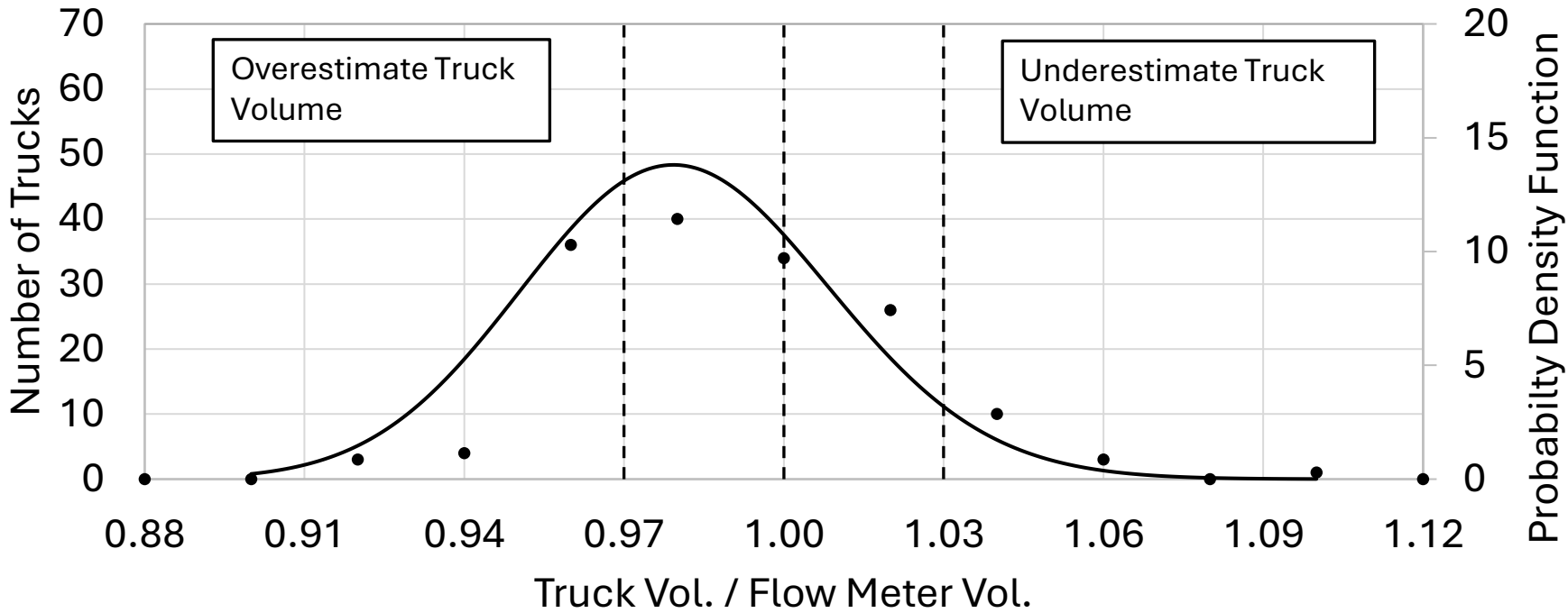
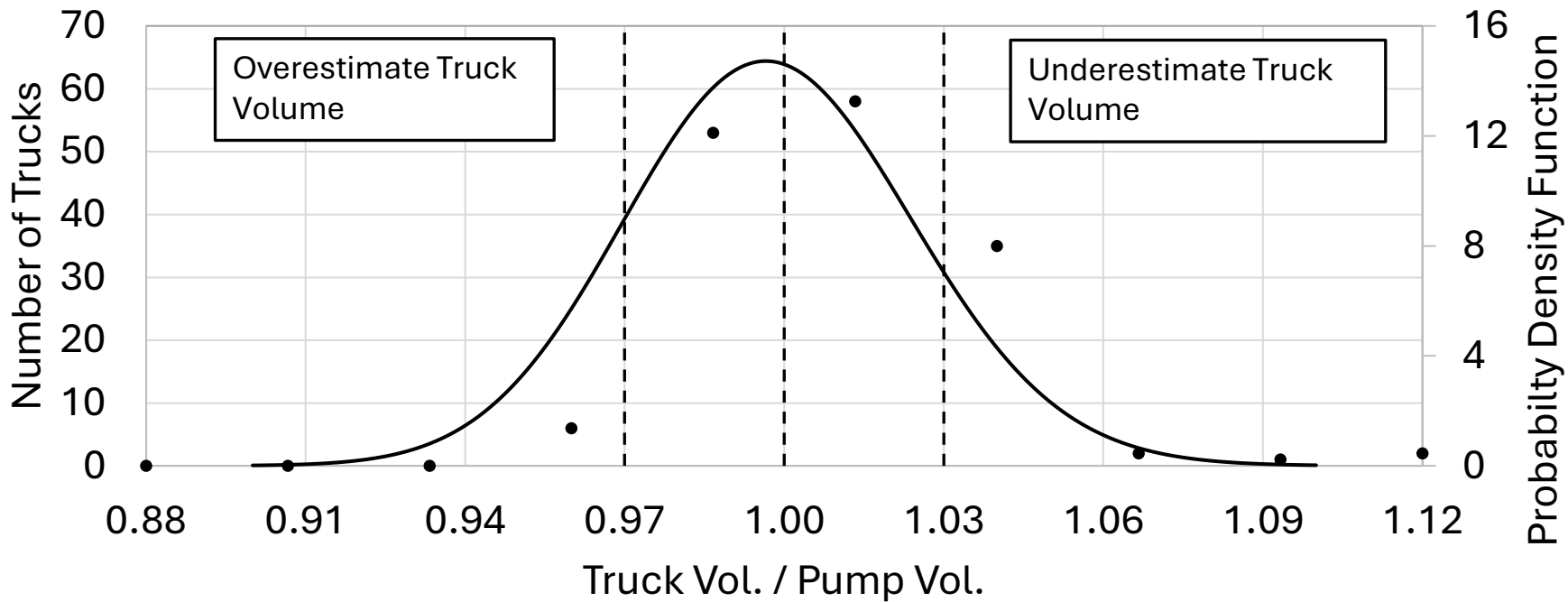
Piles with at least one...	#	%	of	Total Piles Analyzed
Partial Re-stroke during Drilling	203	52.6%	of	386
Complete Re-stroke during Drilling	114	29.5%	of	386
Partial Re-stroke during Grouting	63	16.3%	of	386
Complete Re-stroke during Grouting	25	6.5%	of	386

Comparison of grout volume recording method for single auger cast pile, not within 3% agreement criteria per (FDOT, 2022).



Analysis performed for 651 auger cast piles show 64% fell outside 3% agreement criteria (dashed red lines).





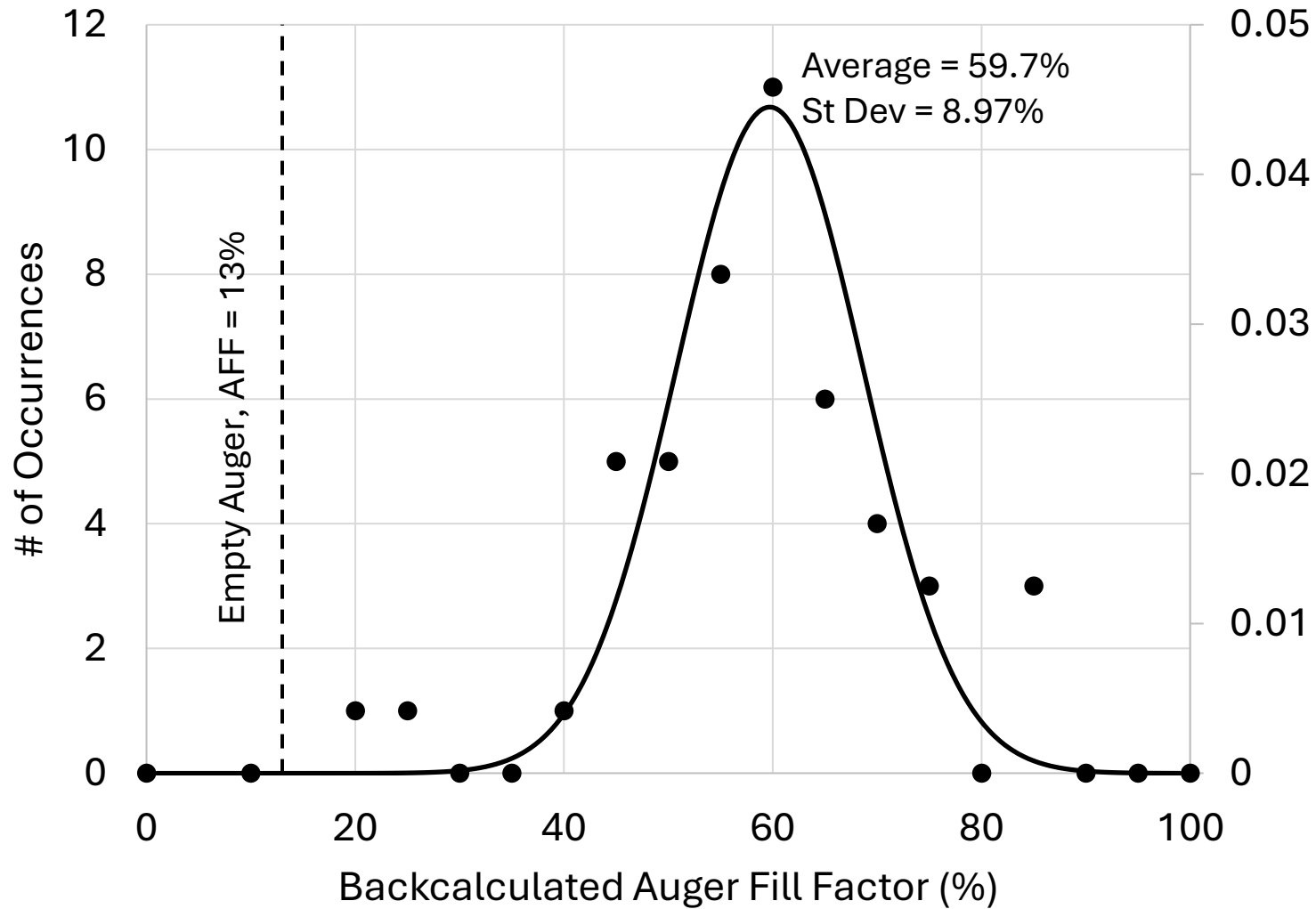
Effect of Incorrect Volume

- Volume = $L A = L \pi R^2$
- 10% overprediction (30in pile) gives
~1.5in error in pile diameter
- Thermal integrity uses placed volume to predict local radius
- $R_{\text{avg}} = \sqrt{\text{Vol} / L \pi}$ proportional to Temp_{avg}

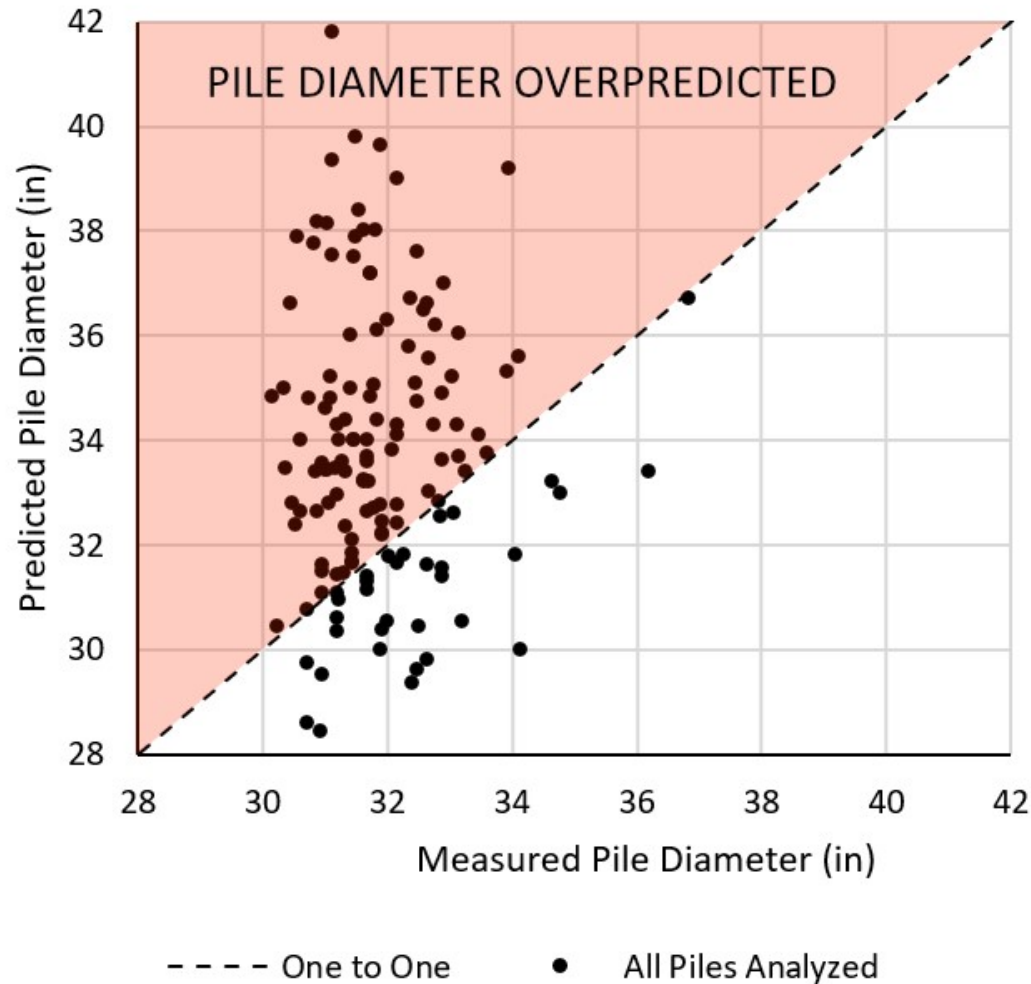
Measured Pile Diameters



Footing Specific AFF (48 piles)



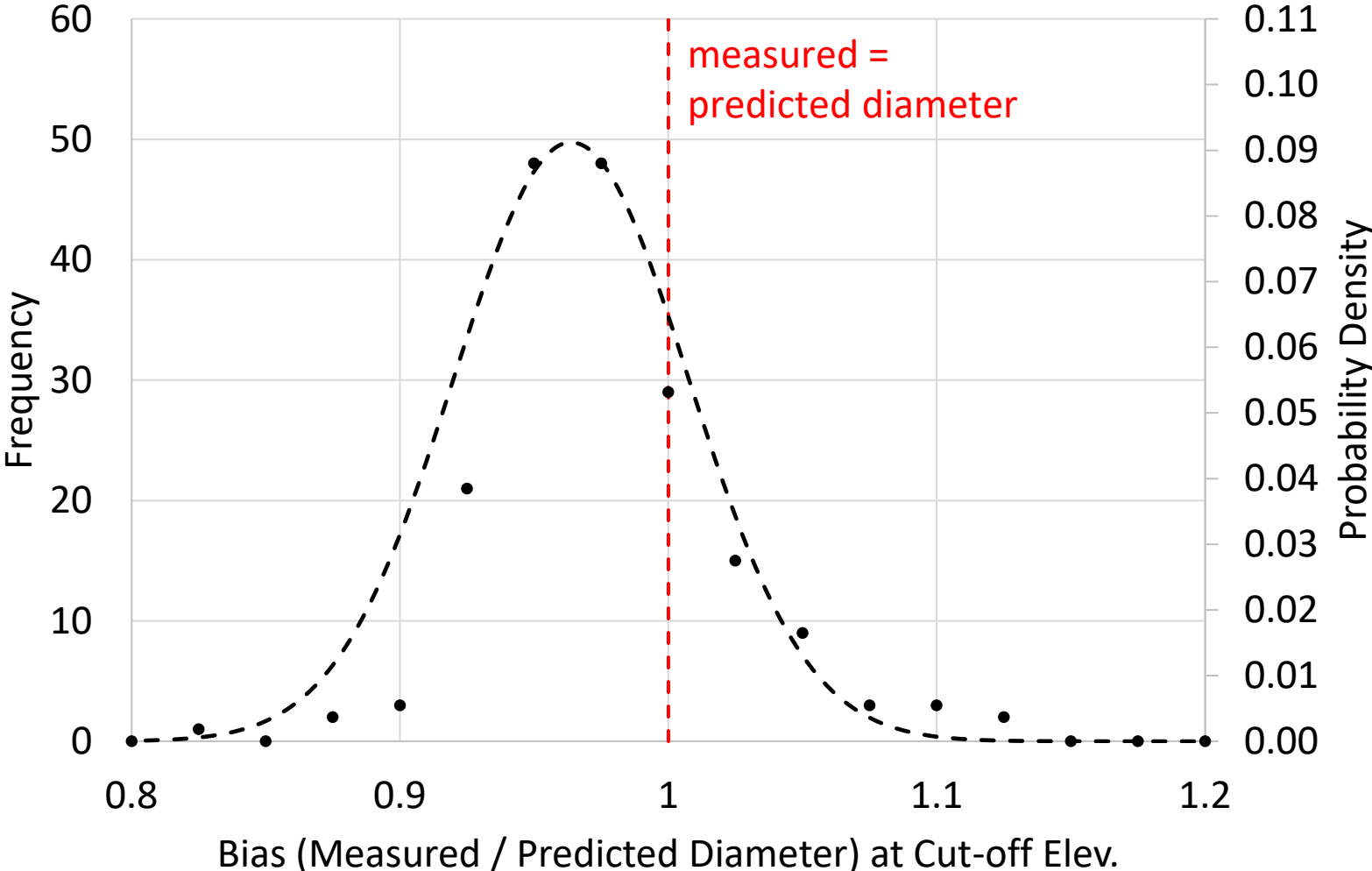
Predicted vs. Measured Pile Diameter



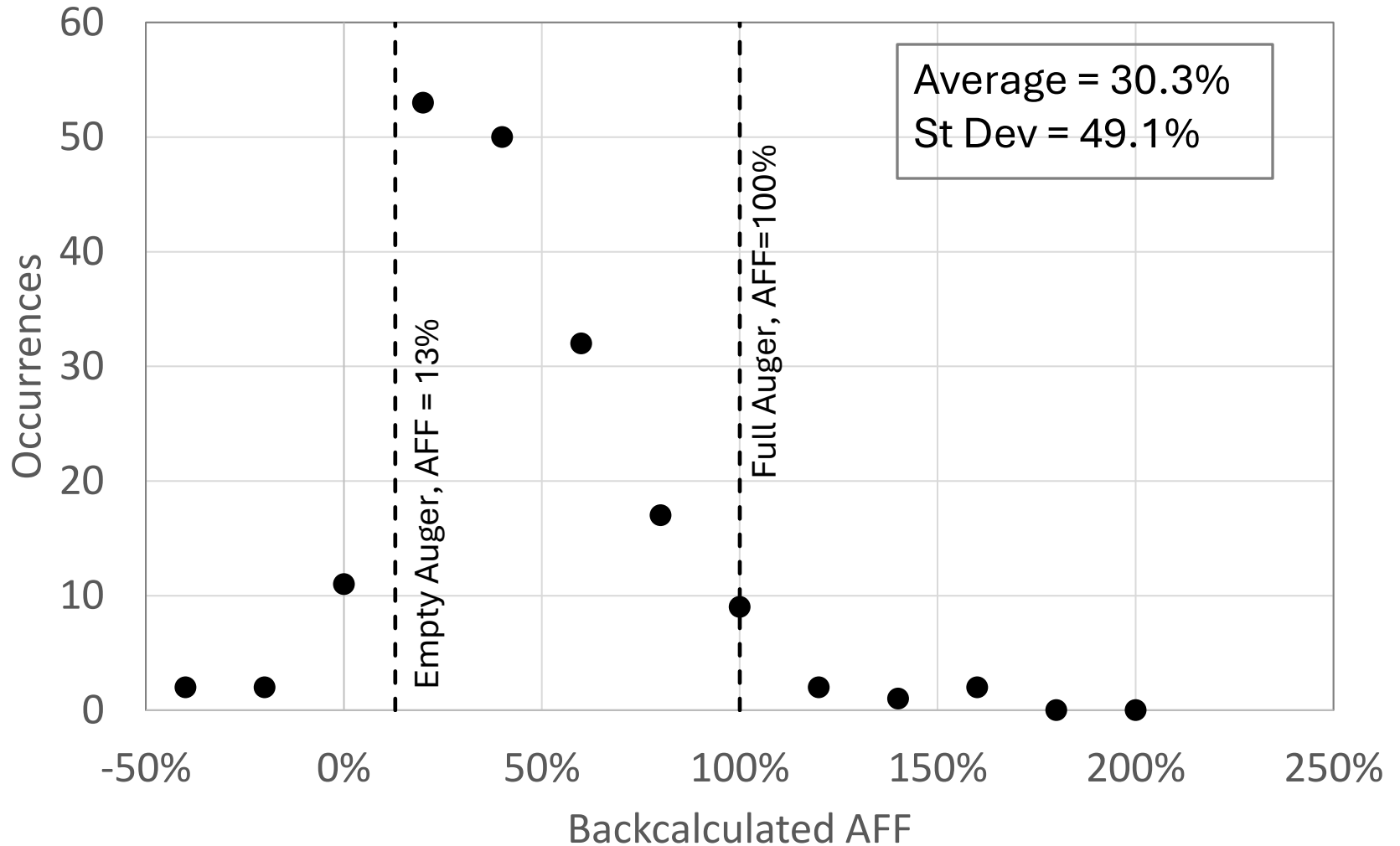
Analysis of as-built dimensions (taken at cutoff elev.) from 139 piles, resulted in 71% of piles being overpredicted.

Measure / Predicted Pile Size

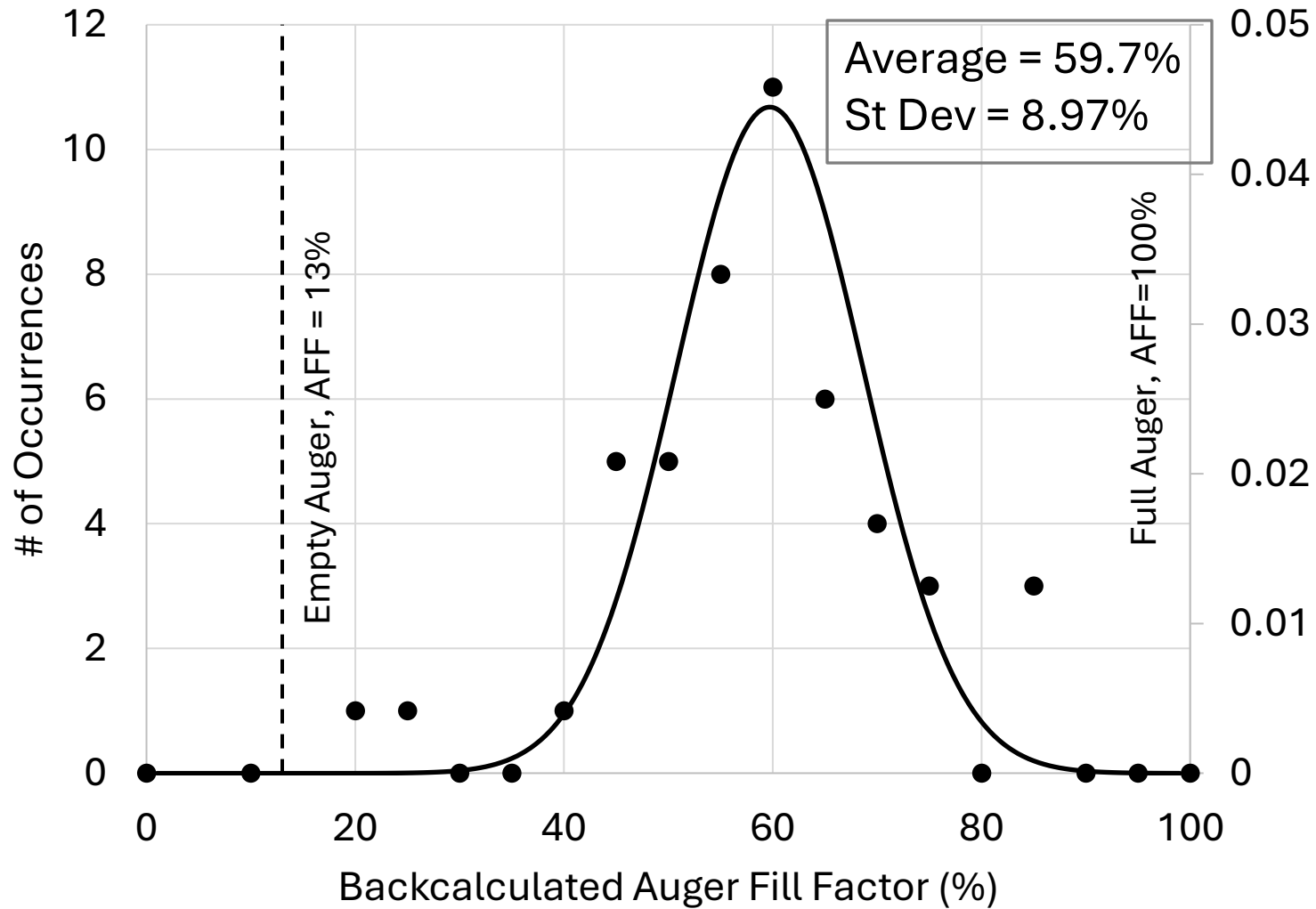
($AFF=0.6$)



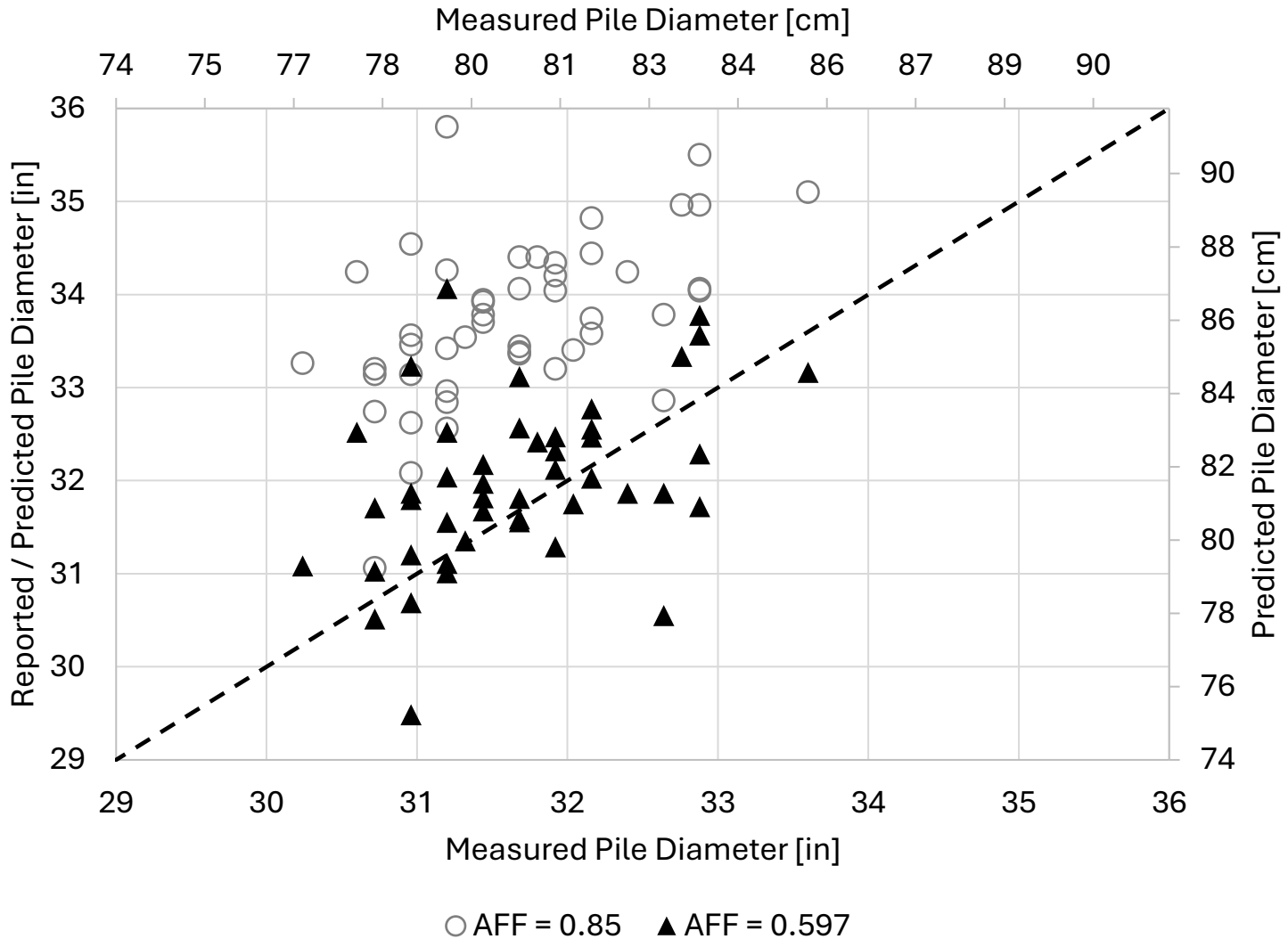
Project Specific AFF (184 piles)



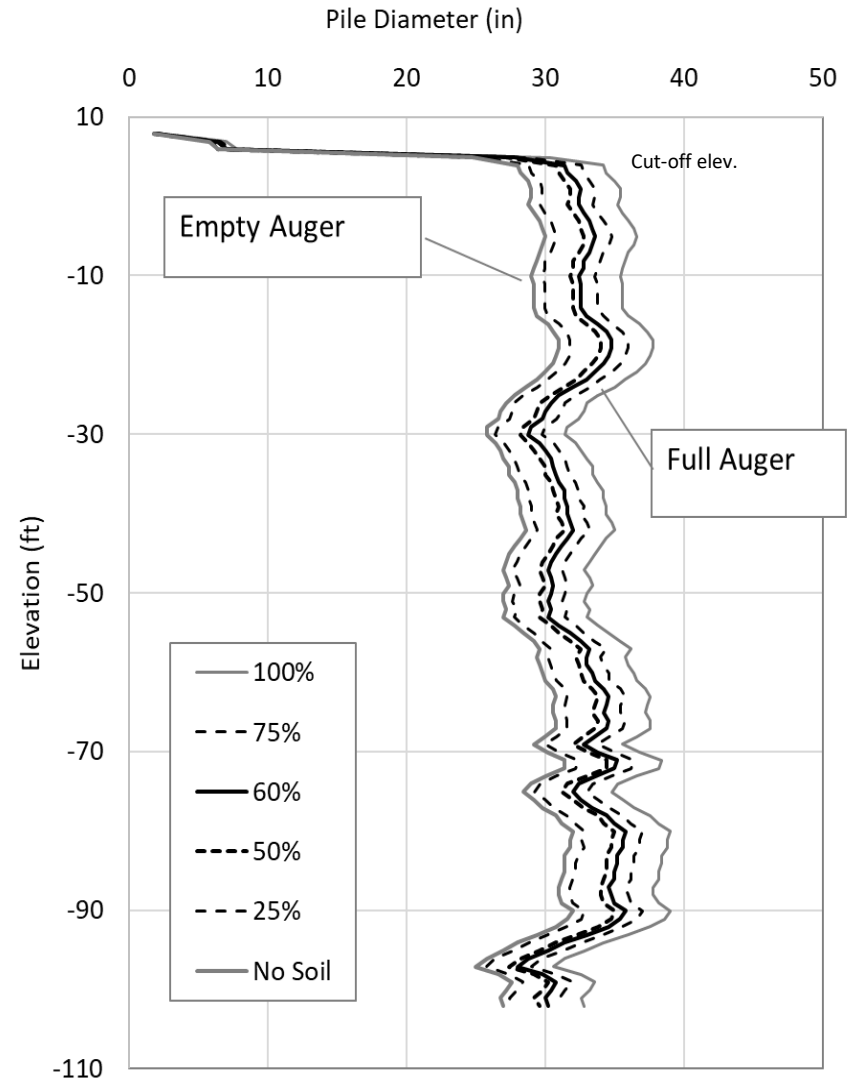
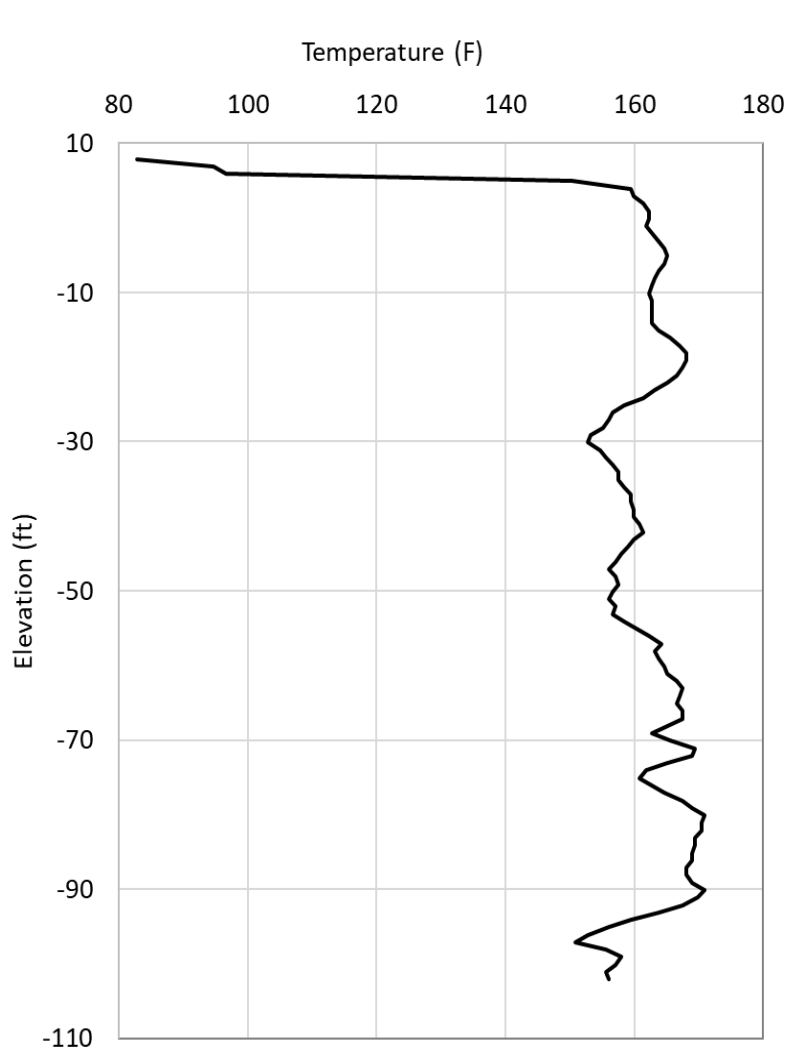
Footing Specific AFF (48 piles)



Site Specific vs Pile Specific AFF



Effect of AFF on pile size calculated from thermal tests



(left) original temperature profile, AFF = 0.6 **(right)** effect of AFF

Pile Specific AFF

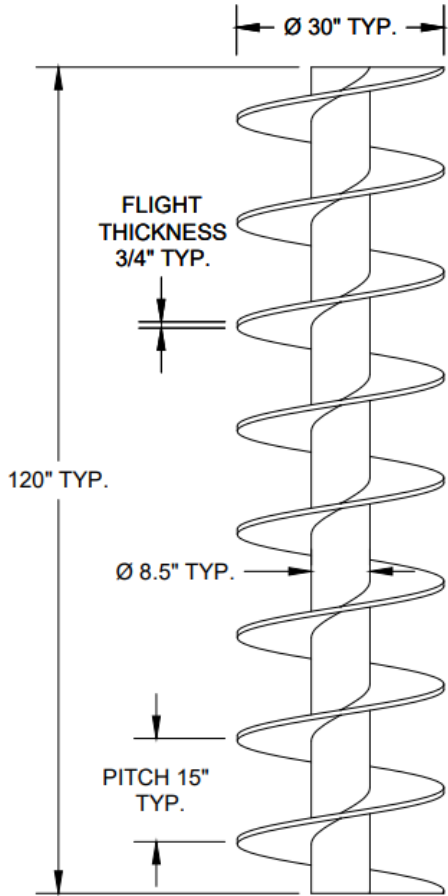
(inspector verified)



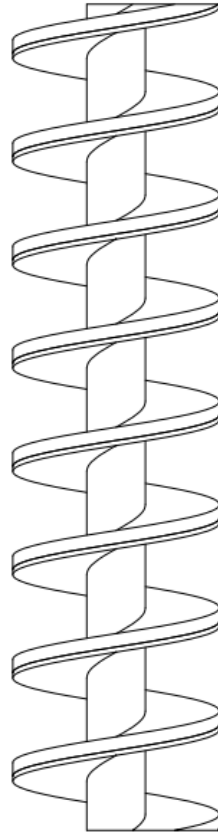
(left) soil clings to center stem **(right)** soil sits on auger flights

Inspector Guide for Pile Specific AFF

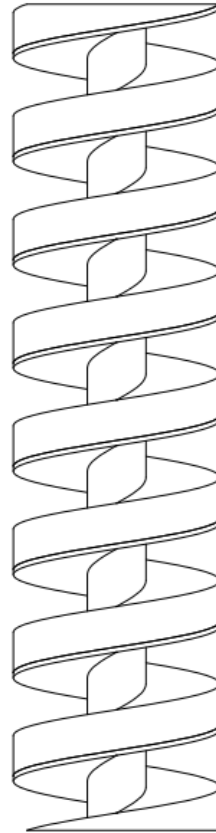
(soil stacked on auger)



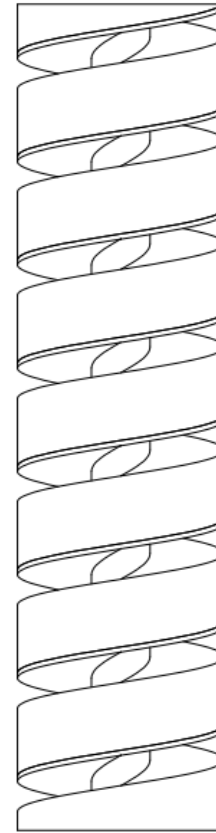
AFF = 0.13
EMPTY AUGER



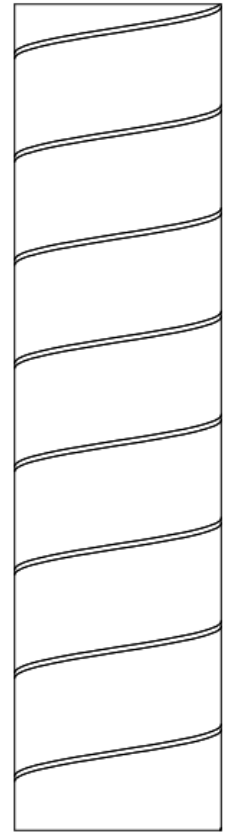
AFF = 0.25
UNIFORM SOIL HEIGHT
OF 2" ON FLIGHTS



AFF = 0.50
UNIFORM SOIL HEIGHT
OF 6" ON FLIGHTS



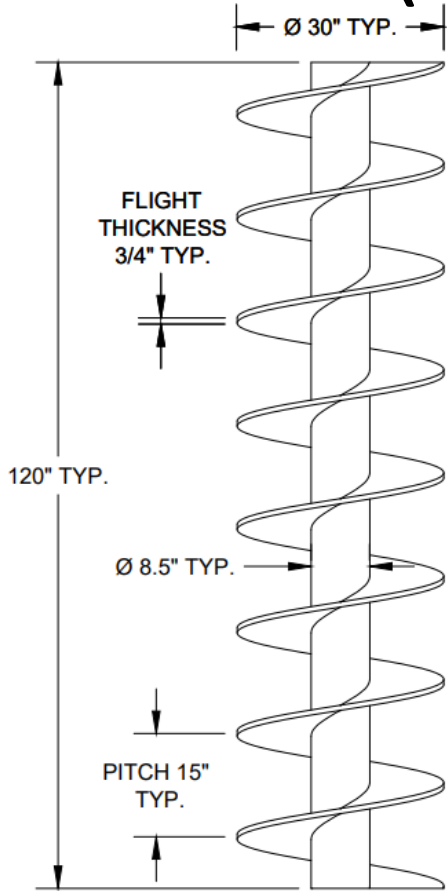
AFF = 0.75
UNIFORM SOIL HEIGHT
OF 10" ON FLIGHTS



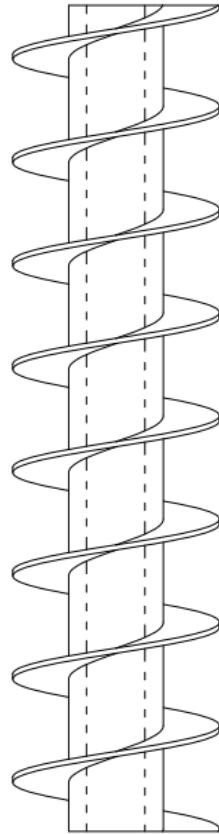
AFF = 1.00
FULL AUGER

NOTE: 10' CENTER SECTION OF CONTINUOUS FLIGHT AUGER SHOWN

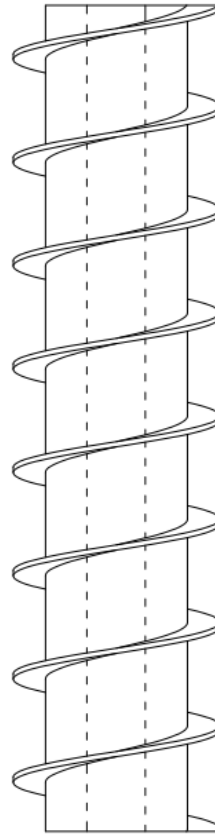
Inspector Guide for Pile Specific AFF (soil clings to auger stem)



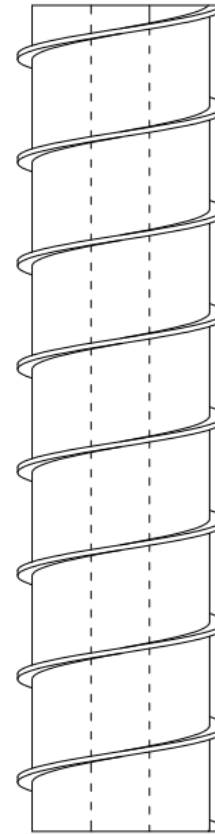
AFF = 0.13
EMPTY AUGER



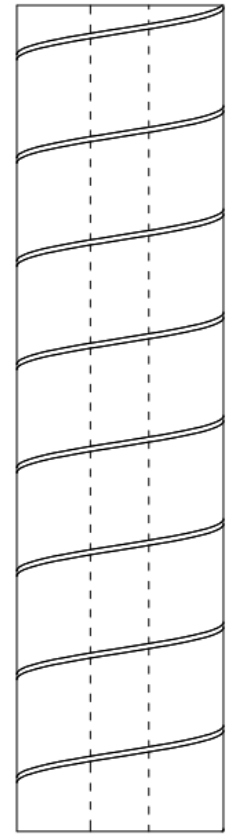
AFF = 0.25
2.5" THICK WALL OF
SOIL WRAPPED
AROUND STEM



AFF = 0.50
6" THICK WALL OF
SOIL WRAPPED
AROUND STEM



AFF = 0.75
8.5" THICK WALL OF
SOIL WRAPPED
AROUND STEM



AFF = 1.00
FULL AUGER

NOTE: 10' CENTER SECTION OF
CONTINUOUS FLIGHT AUGER SHOWN

Conclusions and Recommendations

- Every effort should be made to minimize auger extraction leaving the excavation unsupported; not the focus of the study, but was found to be a recurring scenario.
- FHWA guidelines suggest pump stroke counting to be a poor method of monitoring grout volume. However, this study showed the pump stroke counting method was as good if not better than flow meters.
- A majority of the piles evaluated showed >3% disagreement in volume between flow meter vs pump stroke methods. However, the high R^2 values suggest both systems functioned correctly and a calibration error for one or both was the cause of the disagreement.

Conclusions and Recommendations

- Auger Fill Factors were shown to be viable means of quantifying the unknown/unmeasured portion of the pile grout volume. This helps distinguish between total grout pumped and that which is necessarily overpoured to the ground surface.
- AFF can be determined on a site-specific basis, but a pile specific value from inspector records is recommended.
- A manual of inspector visual aids is provided to assist in the assignment of pile specific AFF values.

Questions?