U.S. Department of Transportation
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Measurement While Drilling (MWD) – The Road to Standardization

2024 Southeast Transportation Geotechnical Engineering Conference

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MWD in Geotechnical Site Characterization

ISO 2016

INTERNATIONAL STANDARD

ISO 22476-15

First edition
2016-08-15

Geotechnical investigation and testing — Field testing —

Part 15:
Measuring while drilling

Reconnaissance et essais — Essais de sol —
Partie 15: Enregistrement des paramètre de forages

Reference number
ISO 22476-15:2016(E)

AASHTO Standard

Standard Specification for

Measurement-While-Drilling (MWD) for Geotechnical Site Characterization

AASHTO Designation: TP xxx-yy[1]

Technical Subcommittee: 1b, Geotechnical Exploration, Instrumentation, Stabilization and Field Testing

Release: Group n (Month yyyy)

AASHTO

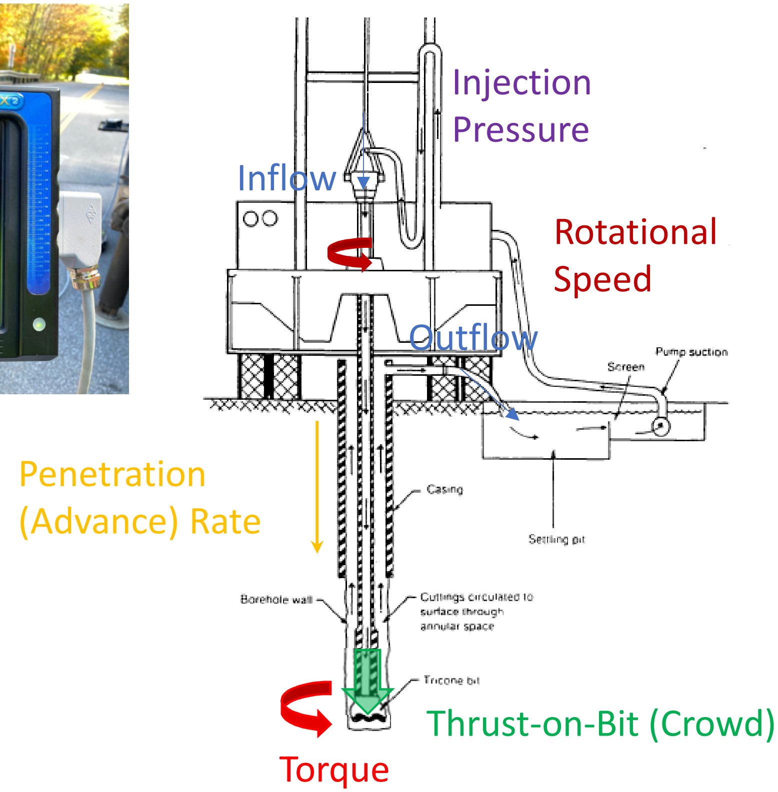
American Association of State Highway and Transportation Officials
444 North Capitol Street N.W., Suite 249
Washington, D.C. 20001

Measurement While Drilling (MWD)

Application of continuous and real-time monitoring and recording of drilling data during the drilling process

<u>Drilling Parameters</u>

- Penetration rate (u)
- Rotational speed (N)
- Flow rate (Q) – Inflow and Outflow
- Torque (T)
- Fluid pressure (P_I)
- Hold-back pressure (P_H)
- Net down-thrust or crowd (F or P_E)



Drilling Parameters

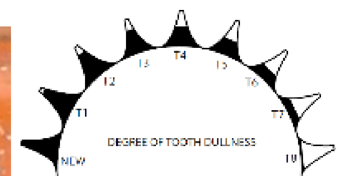
Drilling Parameters Categories:

- **Imposed by drilling method:**
  Tool type and diameter, performance limits of machine, injection system and fluid type.

- **Machine parameters controlled by operator:**
  Thrust on drilling tool, rotation rate, drilling fluid flow rate.

- **Machine parameters from ground response:**
  Advance rate, torque, fluid injection pressure, drilling fluid return rate, holdback pressure.

- **Non-controlled parameters:**
  Tool wear, changes in drilling fluid composition.



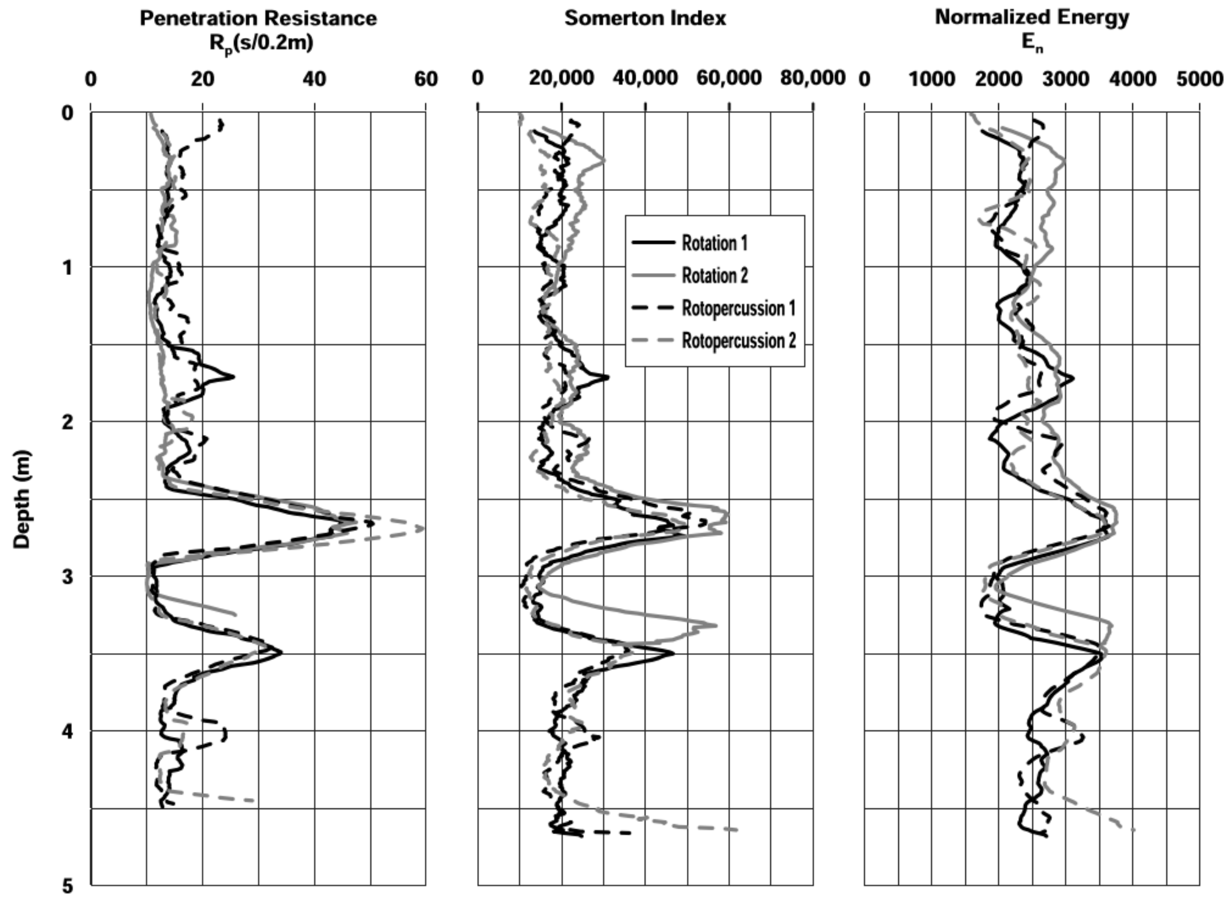
(Benoit, 2024)

Compound Parameters

- Combine individual drilling parameters into expressions of energy or empirical indices
- Reflect the resistance of the geologic material to drilling
- **Normalizing effect** – less dependent on conditions imposed by the driller, the drill rig, and the drilling tools
- Allows site-specific or material-specific expressions to be developed

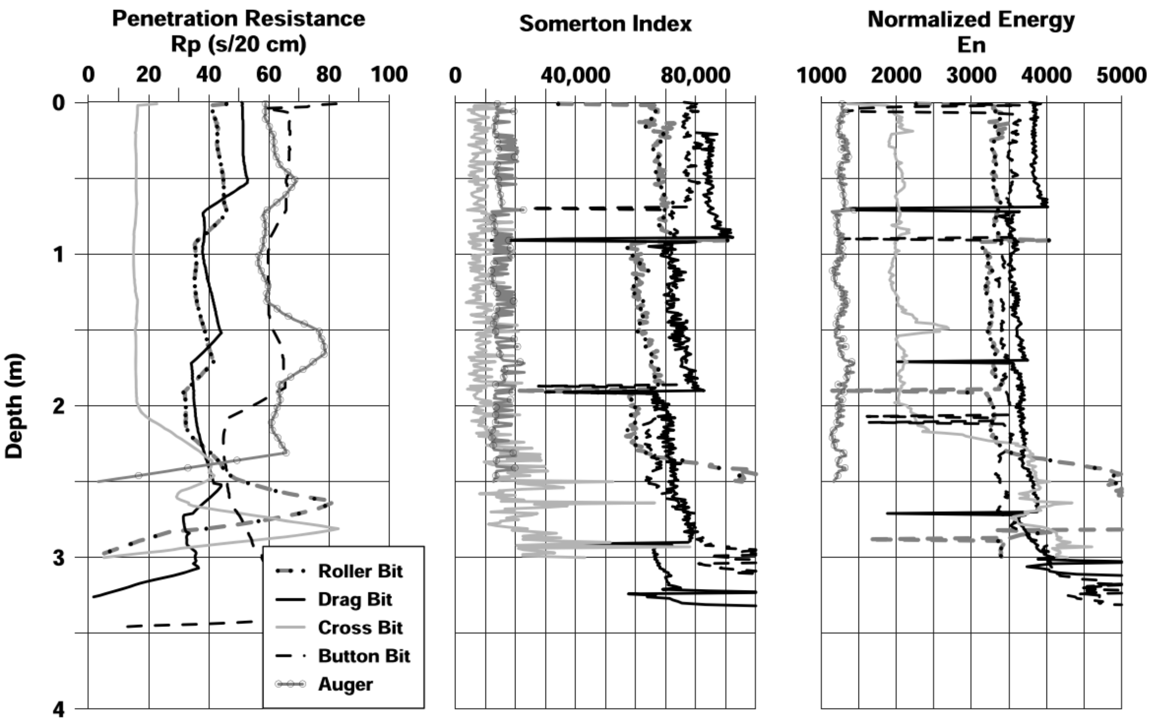
Penetration resistance $$R_P = (t)_{z=0.2\,m}$$	Exponent method $$E = \frac{\log\left(\frac{V}{(N.D)}\right)}{\log\left(\frac{F.D}{T}\right)}$$
Soil-rock resistance $$R_{SR} = \frac{P_E}{u}$$	Drillability strength $$D_s = \frac{64NT^2}{(FuD^3)}$$
Alteration index $$AI = 1 + \frac{W}{W_{max}} - \frac{V}{V_{max}}$$	Somerton index $$S_d = W\sqrt{\frac{N}{u}}$$
Hardness parameter $$\Gamma_{hard} = \frac{N.F.D^2}{(u.T)} \quad \Gamma_{easy} = -\frac{1}{\Gamma_{hard}}$$	Specific energy $$E_s = \frac{F}{A} + \frac{2\pi.N.T}{(A.u)}$$

Drilling Method Differences



(Reiffsteck et al., 2018)

Bit-Type Differences



(Reiffsteck et al., 2018)

Notes from the 2024 MWGC during ADSC Discussion "Our old friend, RQD…"

- RQD is not a great measure for drilled shaft design and constructability

Regarding drilled shaft construction…

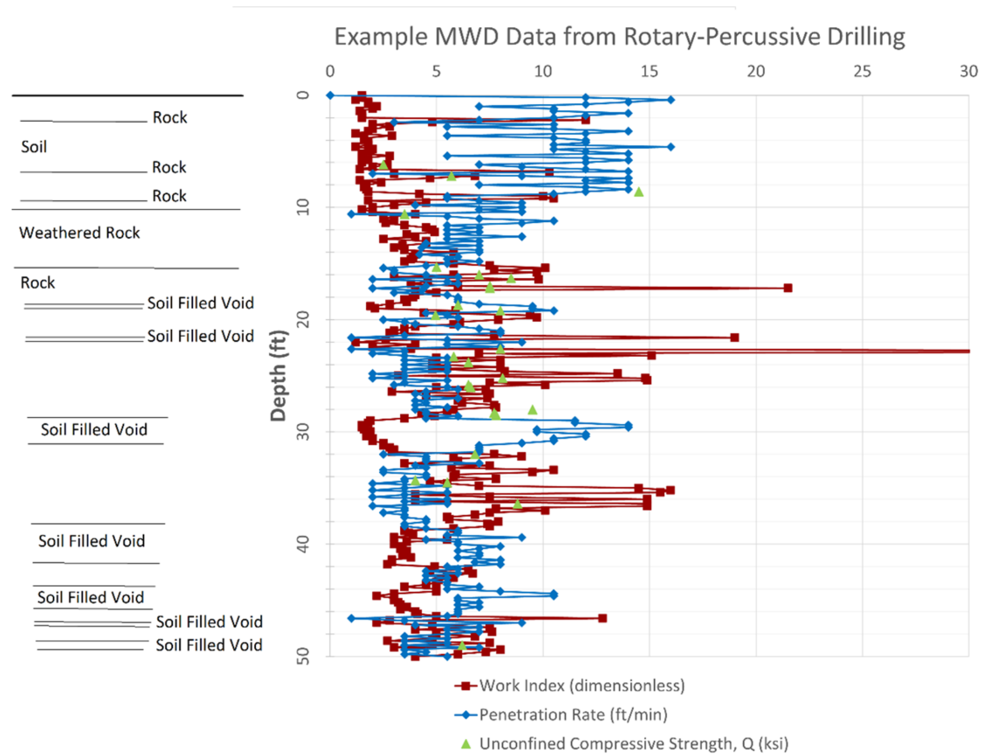
- Groundwater – especially artesian conditions – is problematic
- Discerning rock & rock elevation can be problematic
- Identifying boulders and discerning them from bedrock can be problematic
- "Driller's Notes" are helpful…but we can do better!

Characterization from MWD

Fresh Rock: u < 5 ft/min; WI > 7
Wea. Rock: u ~ 8-10 ft/min; WI ~ 3-5
Soil/void: u > 10 ft/min; WI < 3

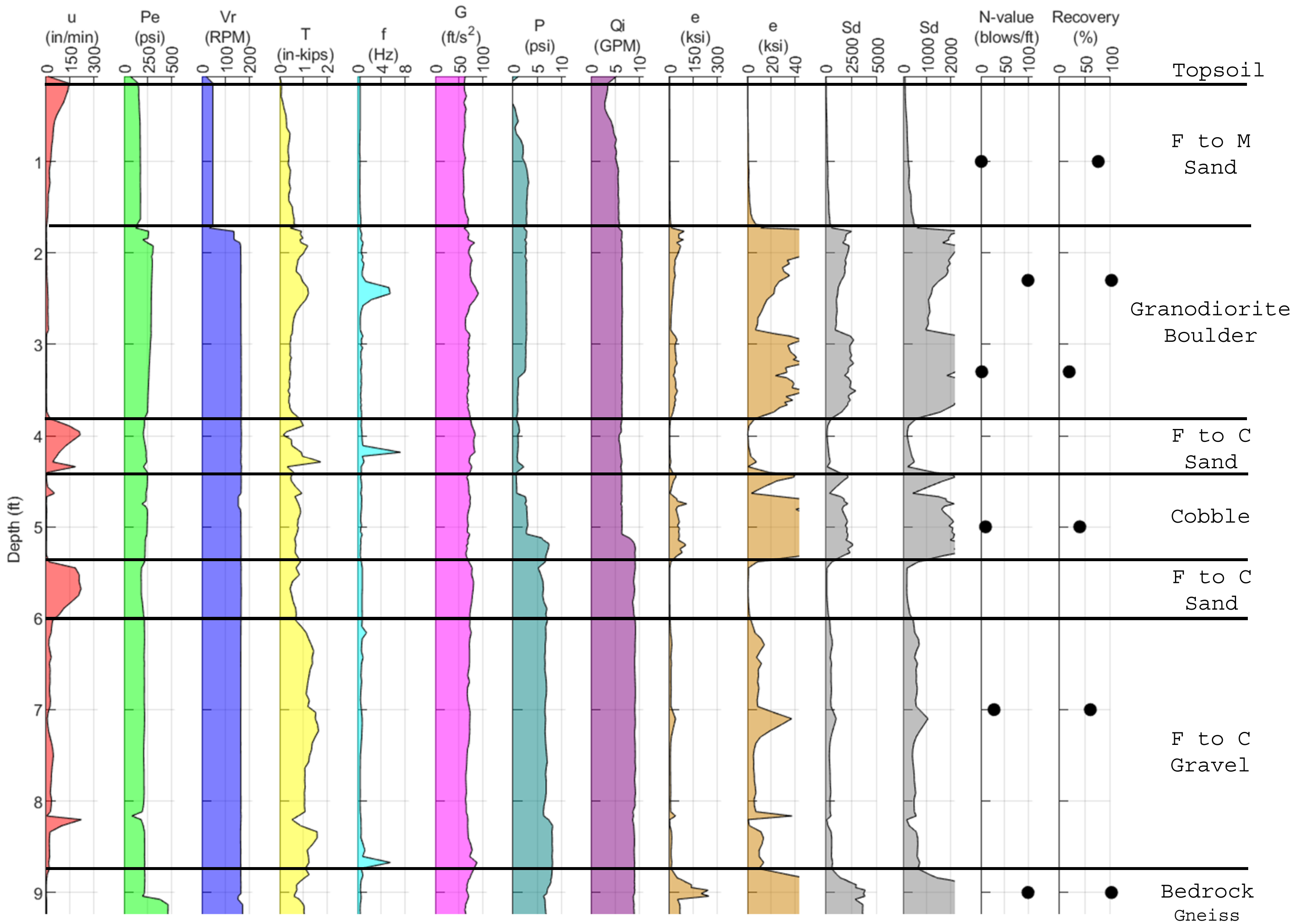
Continuous information

- Changes in strata (soil) and lithology (rock)
- Drilling and penetration resistance (production, correlation)
- Condition and properties
  - Hardness, fracture-frequency, relative weathering, strength
- Anomalies (voids and boulders)
- Verification of conditions and ground improvements (grouting)



MWD Data New Hampshire Soil

Identification of Boulders and Cobbles



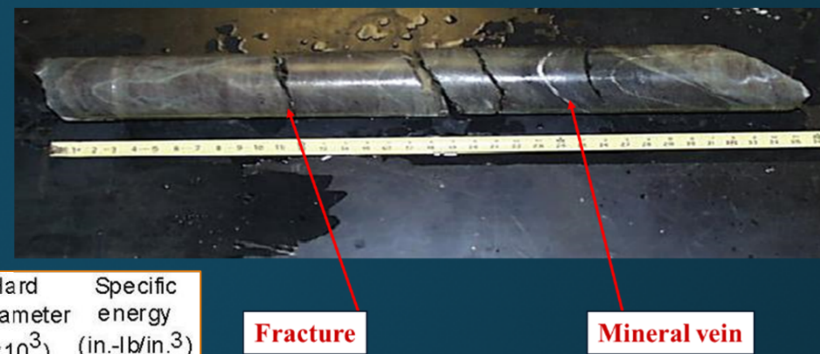
Source: Jean Benoit, University of New Hampshire

Legend:

u	Penetration rate
Pe	Downthrust pressure
Vr	Rotation rate
T	Torque
f	Frequency
G	Acceleration
P	Mud pressure
Qi	Mud flow
e	Drilling energy
Sd	Somerton Index

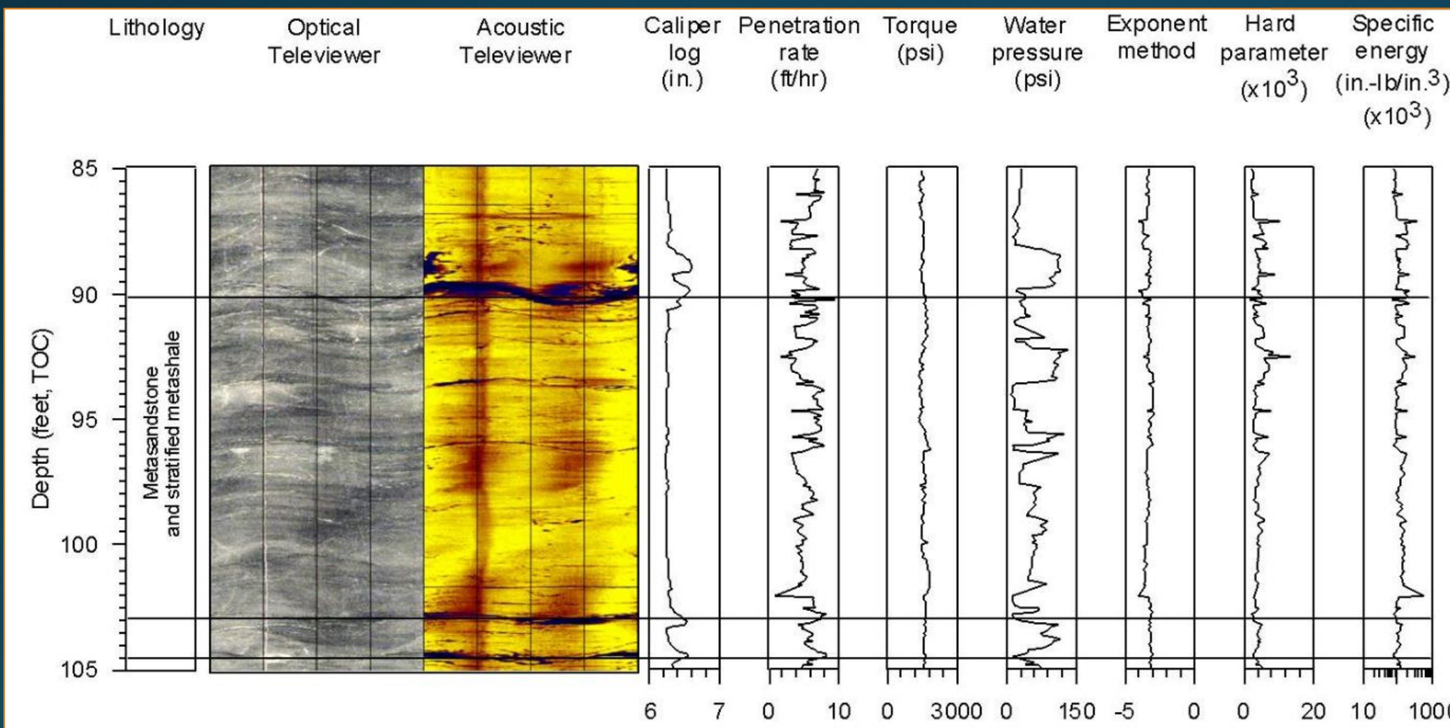
Cored borehole: comparison with geophysical and geological logs

Courtesy of Jean Benoit, from TRB 2022



Fractures at 90.1, 103 and 104.5 ft:

- Penetration rate increases (up to 50%)
- Water pressure decreased
- Specific energy and Hard parameter decreased



6-inch triple core barrel

MWD in Geotechnical Site Characterization

Interest in correlations to …

- UCS in weathered to hard rock
- SPT
- Shear-strength
- Material types
- Relative Density
- Stiffness/Compressibility
- Erodibility of materials for Scour Assessments

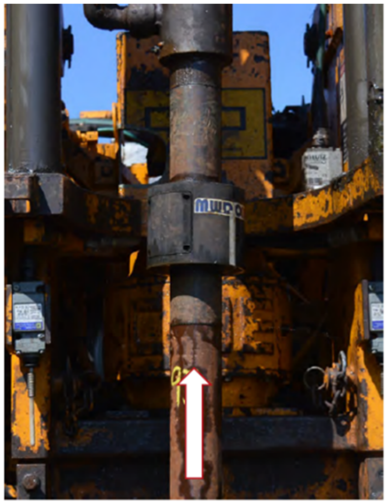
Source: MDT

Drilling Parameters

(Benoit, 2024)

Torque Measurements

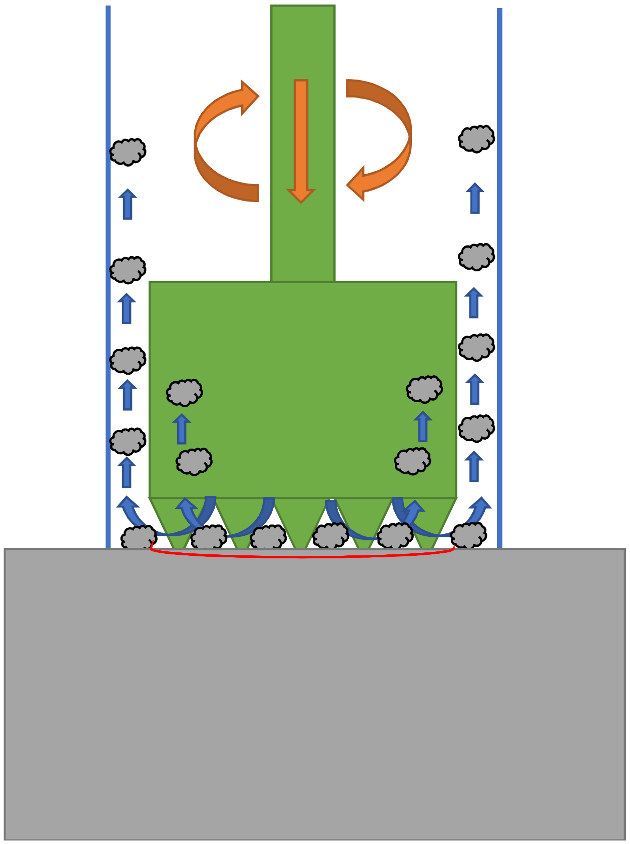
- Hydraulic pressure measurements (must document gear used for actual torque values)
- Wireless strain-gauge torque sensors directly above the drill string (some sensors also measure crowd and rotation rate)
- Instrumented drive shaft



Torque sensor

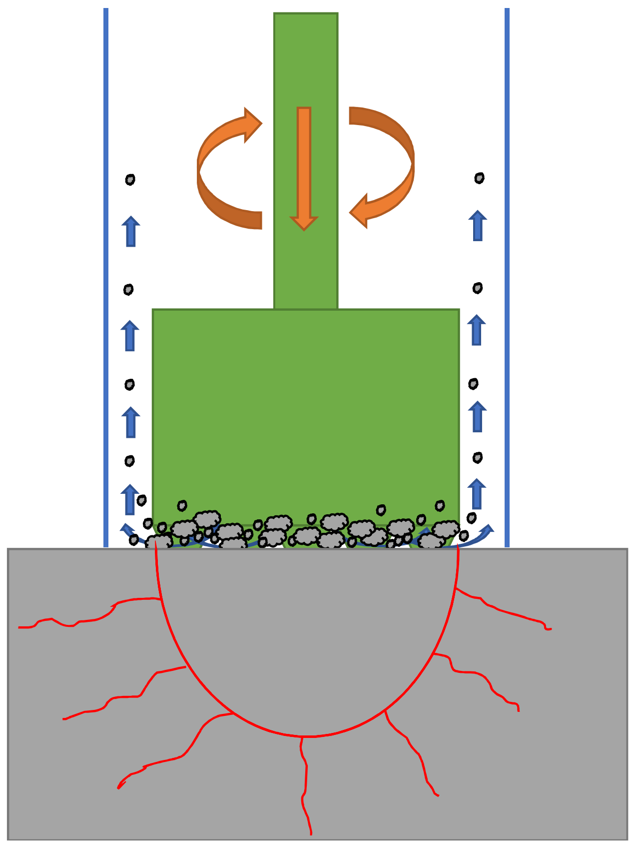
Optimized Drilling

- Proper indentation and cutting → optimized penetration per rotation
- Efficient removal of drilled debris → Larger soil/rock particles removed → minimal energy
- Minimal disturbance to soil/rock prior to strength assessment → Optimized core REC and quality
- In situ strength assessment viable via MWD



Disturbed Drilling

- Overcrowding the bit → Increased torque
- Inefficient flushing → accumulation of drilled debris → smaller soil/rock particles removed
- Increased frictional resistance → High energy
- Increased bit wear and drill rig wear
- Disturbed soil/rock prior to strength assessment
- In situ strength assessment NOT viable via MWD



Optimized

Disturbed

Slide and images from Mike Rodgers, University of Florida, presented at IFCEE 2024

MWD and Drilling Efficiency

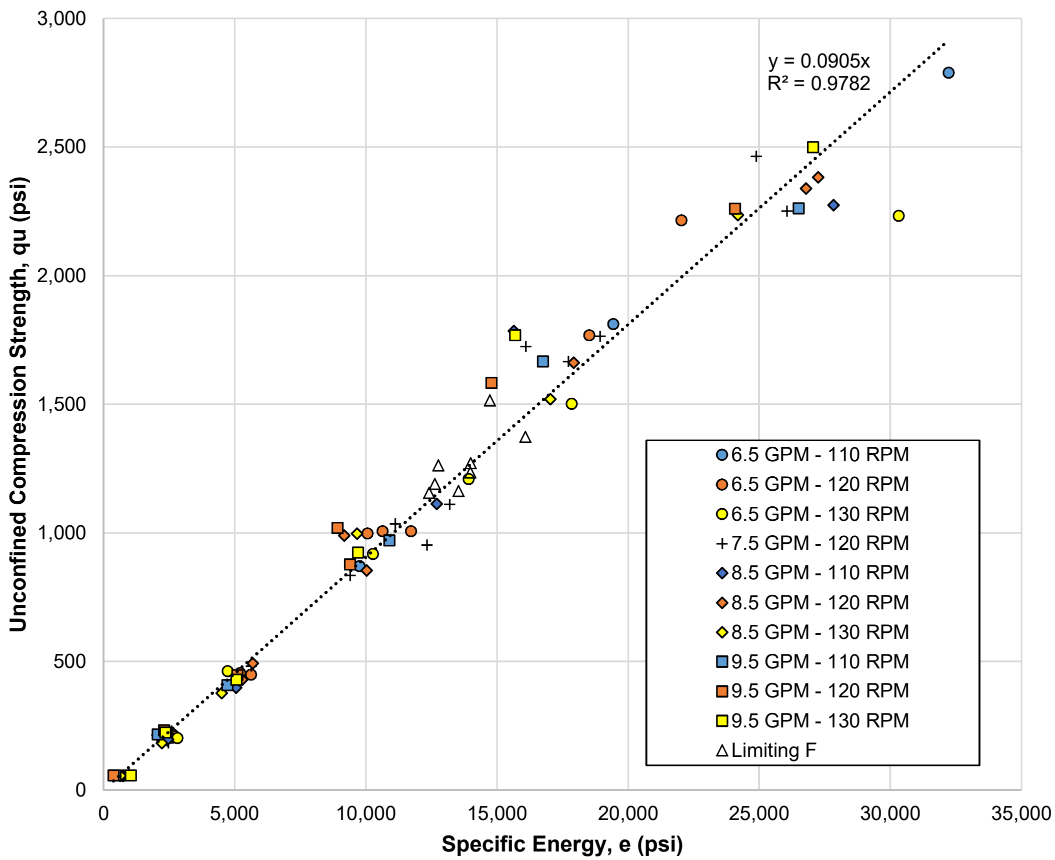
- In rock coring three possible phases of operation exist:
  - Phase 1 – Inefficient
  - **Phase 2 – Optimized**
  - Phase 3 – Destructive
- Use of Phase 2 allows collection of **higher quality core** and **reduced bit wear**
- Identification of the **Operational Limits** for a drilling tool allows the driller to remain in Phase 2
  - Limitations on torque and crowd for a constant penetration rate and rotational speed

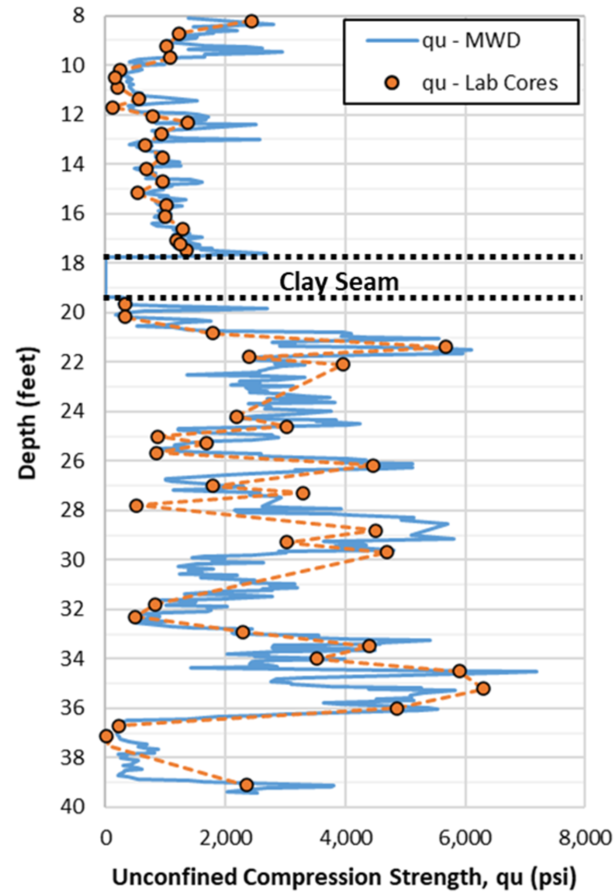
Drilling within the operational limits

Drilling outside the operational limits (Phase 3)

Rodgers et al., 2021

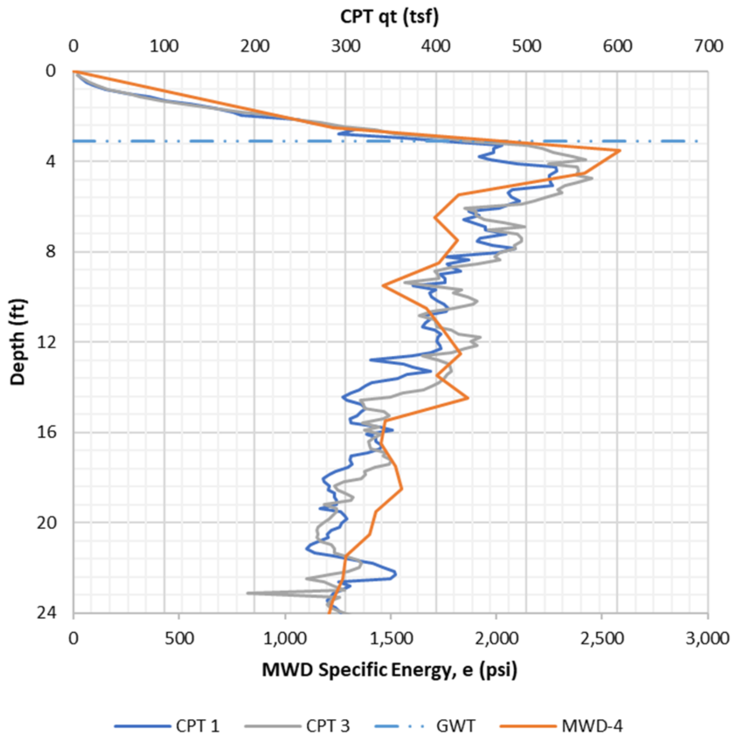
Correlations with Rock Strength

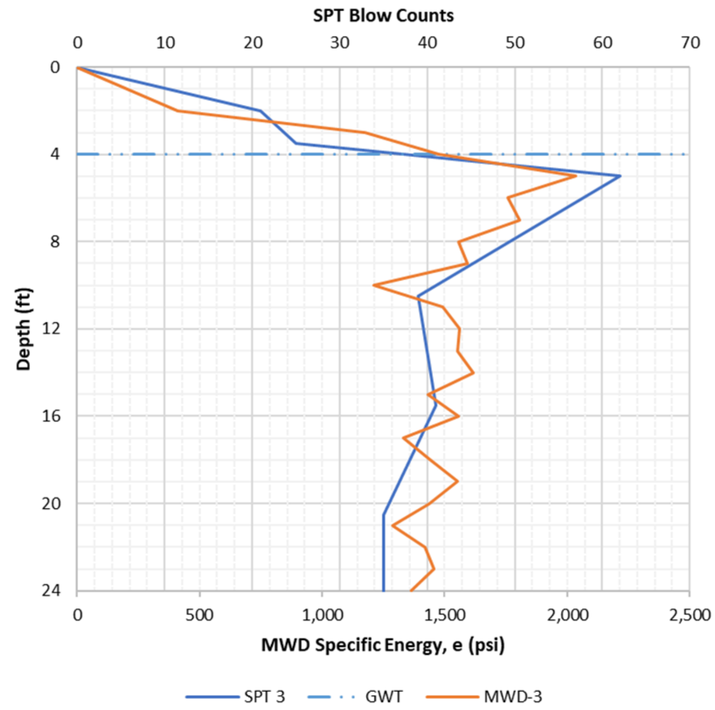




Rodgers et al. (2021)

MWD Compared to Conventional Methods

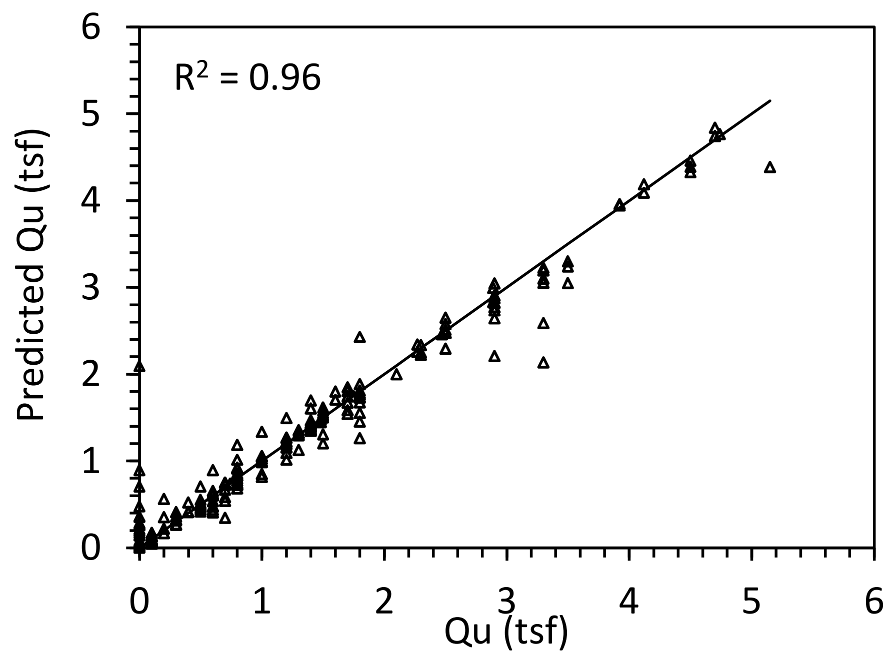




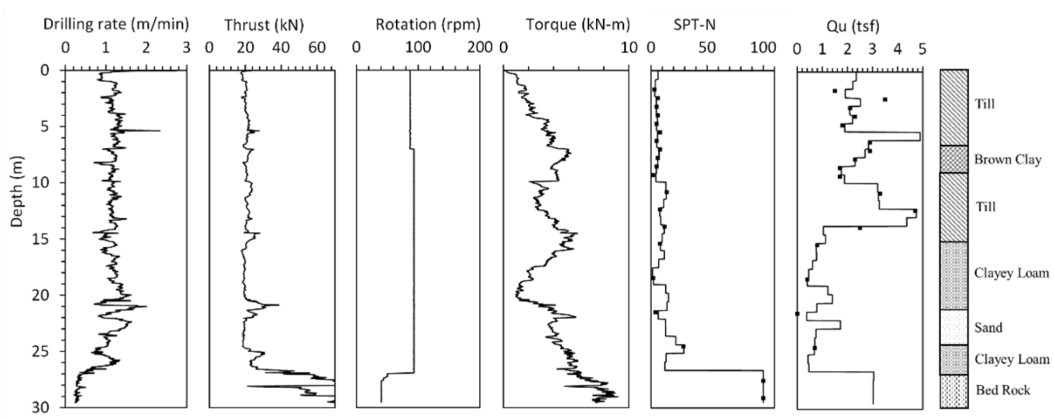
Rodgers, Horhota, and Jones (2024)

MWD in the Future

- Machine learning to predict unconfined compressive strength and SPT N-value



Images from Tugce Baser, University of Illinois, presented at IFCEE 2024



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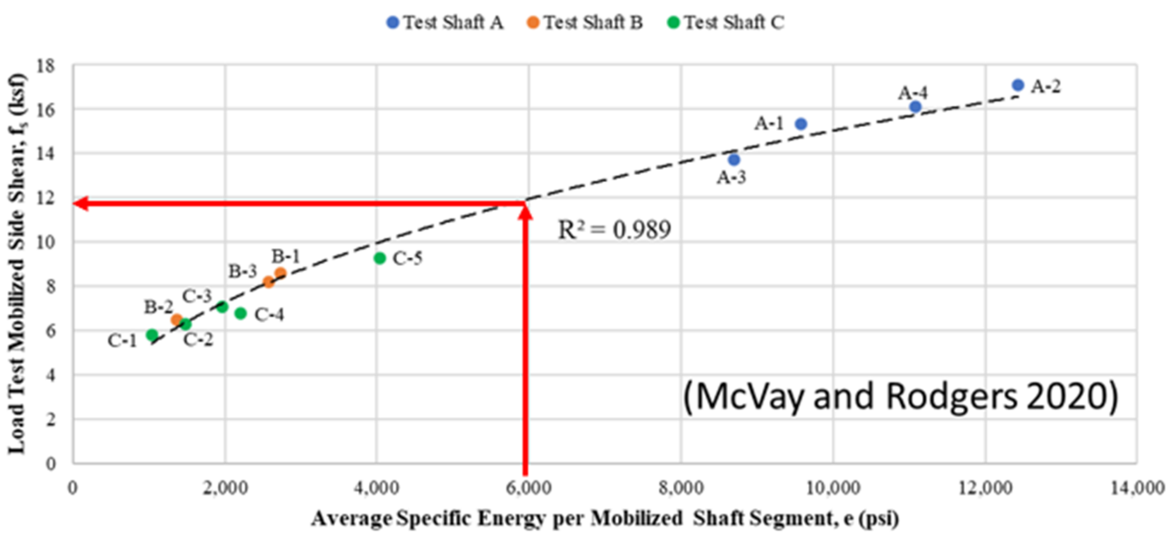
Drilled Shaft QA/QC

- Correlate specific energy calculated using MWD with measured resistance from load tests



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DRAFT

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MWD in Geotechnical Site Characterization

Differences Between European and U.S. Practice:

<u>European Practice</u>

- Fully hydraulic rigs
- Rotary and rotary-percussive methods used
- Torque and crowd measured from pressure transducers
- MWD predominantly used to distinguish materials, voids and boundaries

<u>U.S. Practice</u>

- Both hydraulic & mechanical rigs
- Hollow-stem auger (and shallow solid-stem) also common
- Torque and crowd on mechanical rigs require strain-gauges
- Much interest in engineering correlation, as well (higher accuracy from strain-gauge measures allow for this)

Available under that pile of magazines on your coffee table, or at www.readgeo.com

MWD Users Group

- Forum for interaction among MWD users
- Joint industry group in cooperation with
  - State DOTs
  - FHWA
  - ASCE G-I
  - DFI
  - TRB
- Hosted by Deep Foundations Institute
- Presentations from users and manufacturers, discussions
- Started in October 2021, 50-90 attendees per session
- ALL ARE WELCOME TO JOIN!

Geo-Industry Technology Users Groups