Micropile Installation Methods and Selection

Dr. Donald A. Bruce

DFI ADSC GEOSYSTEMS, L.P.

Agenda

1. Drilling in Rock and Overburden
   1.1 Methods
   1.2 Flushing Characteristics
   1.3 Monitoring While Drilling
2. Grouting
   2.1 Classification of Micropiles Based on Grouting Method
   2.2 Means, Methods and Materials
   2.3 QA/QC
3. Storage Handling and Placement of Reinforcement
4. Growth of the Micropile Market in the U.S.
5. Final Remarks

1. Drilling in Rock and Overburden
1.1 Methods

Scope and Commonalities

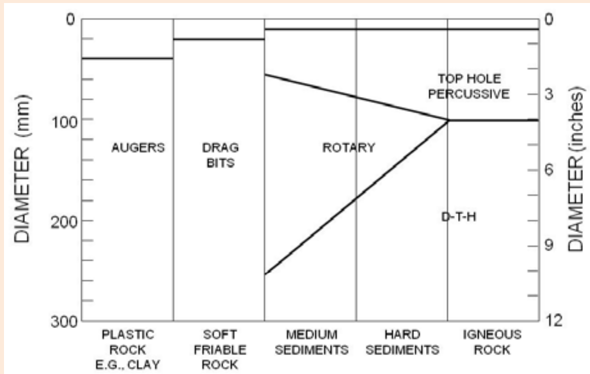
- Scope
  - Typically 3 to 12-inch diameter.
  - Typically ≤ 200-foot depth.
  - Typically within 30° of vertical or horizontal.
  - Mostly beneath the water table.
  - Required in all types of ground, natural or placed, unconsolidated or lithified, and will often encounter obstructions.
  - May face Federal regulations, e.g., USACE 1997.
  - Must cause minimal damage to the ground or existing structures.
  - Must allow completion of the hole in one day.
  - Must be consistent and able to be controlled and monitored.
- Generally contractor-driven (“performance specification).

Scope and Commonalities (continued)

- Continuous, straight penetration
- Constant diameter, stable and clean bore
- Consistent with the purpose of the drill hole (e.g., grout hole vs. anchor hole)
- Appropriate combinations of thrust, torque, rotation, percussion, flush
- Cost effective
- Dictated by ground, not historical bias
- Environmentally compatible

Evolution of Rock Drilling Methods

Dawn of the ADSC Age

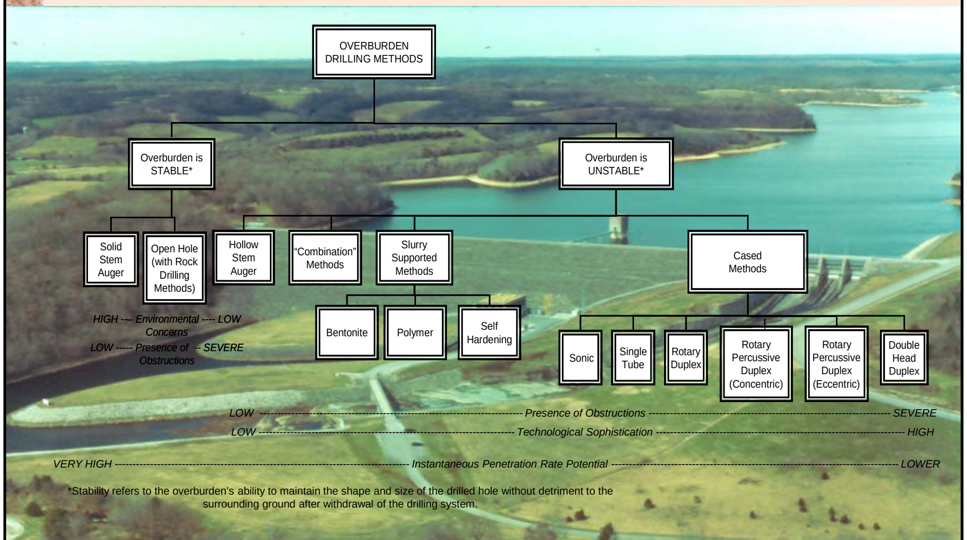


Basic drilling method selection guide for rock using noncoring methods, Littlejohn and Bruce, 1977 (adapted from McGregor 1967).

Rock Drilling Methods (Disco Era)

- Rotary
  - High rpm, low torque, low thrust (blind or core)
  - Low rpm, high torque, high thrust
- Rotary Percussive
  - Top Hammer
  - Down-the-Hole Hammer
    - Direct circulation
    - Reverse circulation
    - Dual fluid drilling
    - Water hammers
- Rotary Vibratory (Sonic)

Overburden Drilling Methods



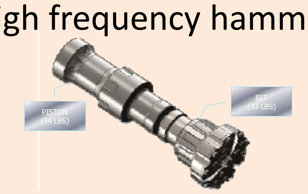
Basic drill method selection guide for overburden (Bruce, 2003).

Notes on the 2003 Classification

- Basic subdivision is stable vs. unstable. Stable overburden can be drilled with SSCFA or rock drilling methods (e.g., rotary with air).
- Most overburden is unstable – especially when holes are long and in "difficult" urban settings.
- Unstable methods are subdivided into 4 categories:
  1. HSA – but be careful.
  2. "Combination" methods – can offer original and effective project solutions.
  3. Slurry-supported methods – organic polymers offer considerable advantages over bentonite.
  4. Cased methods – now 5.

Some Evolutionary Notes

- DTH usually superior to Top Drive or Rotary in Rock
  - penetration rates
  - per foot costs
  - deviation control
  - large diameter (< 40 inches) to greater depths (> 300 feet)
- Very sophisticated computer programs/simulations optimize design for speed, durability, reliability and for special applications (e.g. “short” hammers and high frequency hammers).



New Piston-Bit Combination (Equal Mass)

New Simple, High Frequency RX Hammer

Some Evolutionary Notes
(continued)

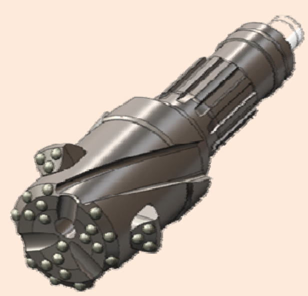
- Air pressures have increased from 160-250 psi in 1970’s, to up to 500 psi today.
- Better understanding of metallurgy of components and bits.
- More widespread use of reverse circulation.
- More widespread use of water powered DTH’s – efficiency, lower flushing velocities, straighter holes.
- Use of rotary vibratory methods (Sonic) but mainly for overburden, “the only true innovation to come to the drilling industry since the Chinese invented cable tool drilling some 3,000 years ago” (Roussy, 2002).

More Recent Developments

These include:

- Numa “Superjaws” – featuring 2-4 “wings” which open by pressure on the face of the hole. Direct descendent of old Acker Casing Underreamer System.
- Atlas Copco “Elemex” system – a ring on the casing redirects the air flush away from the DTH bit face and so makes it easier to control.
- Center Rock “Rotoloc” system – features a patented method of extending, locking and retracting cutting wings on the central pilot bit, in a very simple and reliable fashion. Does not rely on downwards pressure on the face and leaves nothing behind in the ground.

Roto-Lock (retracted)



Roto-Lock (extended)

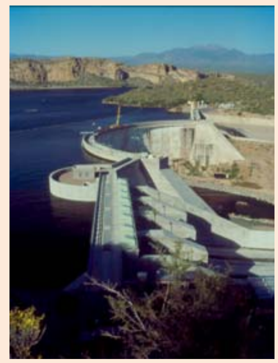
1.2 Flushing Characteristics

- Up-hole velocity (UHV) > "sinking velocity"
- In water, sinking velocity (V_z) is $V_z \approx 10^6 \times d^2$ m/s where d is the diameter of the particles.
- Ability of flush to carry or suspend cuttings dependent on:
  - rate of flow of fluid
  - Viscosity of fluid
  - size and shape of cuttings
  - s.g. of fluid and cuttings
- UHV (m/min) =

$$\frac{1274 \times \text{Flush Pump Rate (Liters/min)}}{D^2 - d^2 \text{ (mm)}}$$

where D = drill hole diameter (in mm)

d = drill string diameter (in mm)

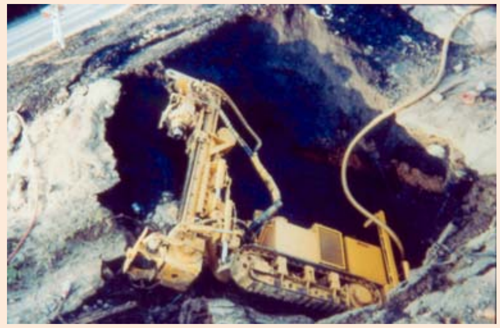


Acceptable Up-hole Velocities.

Drill Flush Medium	*Recommended Uphole Velocity*
Air or air–water mist	1500 m/min (maximum 2100 m/min)
Water	36 m/min (maximum 120 m/min) (i.e., at least 20 times less that for air)
Medium viscosity mud (35-s Marsh)	30 m/min
Thick mud (more than 50 s Marsh)	18 m/min
Foam	12 m/min

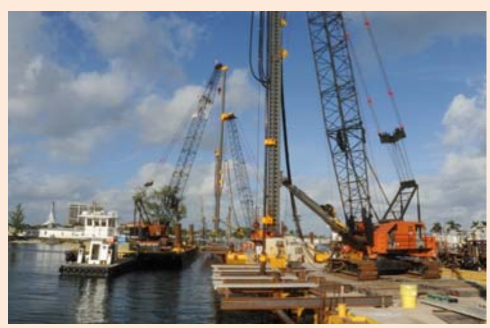
Source: Australian Drilling Industry Training Committee Ltd. 1997, with permission from Taylor & Francis.

Drilling Flush Characteristics



- Air vs. Water – Rotary vs. Rotary Percussion
- Guideline for selection:
  - Provide clean hole
  - Enhance penetration rate
  - Minimize tool wear
  - Consistent with purpose of hole
  - Minimal damage to formation and/or structures
    - Environmentally compatible
    - Reconsider options if “lost flush” occurs

1.3 Monitoring While Drilling



- Fundamental Concept
- Manual Monitoring
- Automated Monitoring
- Benefits to Owner and Contractor (not covered in this presentation)

Basic Principles of Monitoring While Drilling (MWD)

Fundamental Concept

Every hole that is drilled in the ground is a potential source of information on the properties and response of the ground. This obviously applies to designated site investigation holes, but is equally true of every production hole, such as drilled for anchors, micropiles, nails or grout holes. Such information can be collected by two basic methods: manual and automatic. The data must be studied in real time to be useful.

Examples:
1. Helps determine or verify appropriate bond zone horizons for anchors and micropiles.
2. Secondary and higher order holes will demonstrate progressive densification of ground in compaction grouting projects.
3. Helps select appropriate jet grouting parameters.
4. Will provide a mechanical and hydraulic "picture" of the rock mass at each phase of a grout curtain project.

Basic Principles of Monitoring While Drilling (MWD)

Manual Monitoring

- The value of routine drillers' logs can be greatly enhanced by periodic recording of:
  - penetration rate
  - thrust
  - torque
  - flush return characteristics (cuttings, volume)
  - drill "action"
  - interconnections between holes
  - hole stability
  - groundwater observations
- These data can easily be recorded by a good driller who has been briefed about the overall purpose of the project and so understands what to look for.
- These data should be recorded at 5 ft maximum intervals.

Basic Principles of Monitoring While Drilling (MWD)

Automated Recording of Drilling Progress and Parameters

- Value of real time continuous monitoring for design purposes (manual vs. automatic)
- Look for "exceptions and unexpecteds" [Weaver, 1991]
- Indication of progressive improvement (e.g., denser, less permeable conditions)
- Concept of specific energy
- Several generations/evolutions as software and hardware evolve

Automated Monitoring

Calculation of Specific Energy

$$e = \frac{F}{A} + \frac{2 \pi N T}{AR}$$

where

e = specific energy (kJ/m3)

F = thrust (kN)

A = cross sectional area of hole (m2)

N = rotational speed (revolutions/second)

T = torque (kN-m)

R = penetration rate (m/sec)

2. Grouting

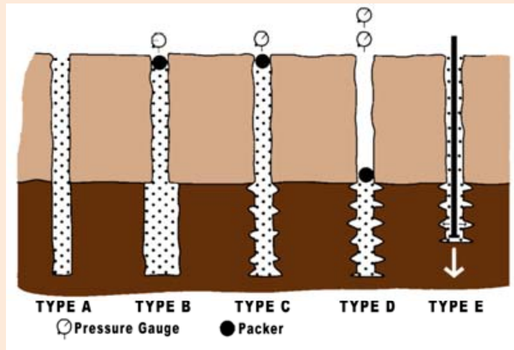
2.1 Classification of Micropiles Based on Grouting Method

Grouting and Grout Function

- Transfers loads from reinforcement to surrounding ground
- May be load-bearing portion of pile
- Protects steel reinforcement from corrosion
- May be used as drill fluid during initial drilling
- Secondary/Post grout enhances soil/grout bond further
- **Basis for Micropile Classification**

Classification Based on Grouting Method

- **Type A**: Gravity
- **Type B**: Pressure grouting through casing
- **Type C**: Single, global post grout
- **Type D**: Multiple, repeatable post grout
- **Type E**: Injection bore bars



Gravity Filling Techniques (Type A)

- Grout introduced into the drill hole through a tremie pipe exiting at the bottom of the hole
- No excess pressure is applied
- This type and phase of grouting is referred to as the *primary treatment*
- Typically only used when pile is founded in rock, or when low-capacity piles are being installed in stiff or hard cohesive soils

Pressure Grouting Through the Casing (Type B)

- Grout injected under controlled pressure through pressure cap on top of drill casing (often the drilling head itself)
- Additional grout injected under pressure after primary grout has been tremied (as temporary casing is withdrawn)
- Enhances grout/soil bond characteristics
- Can be limited to the load transfer length within the design-bearing stratum, or extended to the full length of the pile

Post-Grouting (Types C and D)

- Additional grout injected via grout tubes after placing of primary grout
- Higher water content grout used
  (w/c ratio = 0.5 to 0.75)
- High pressures used (> 1 MPa)
- Type C only used in France to date

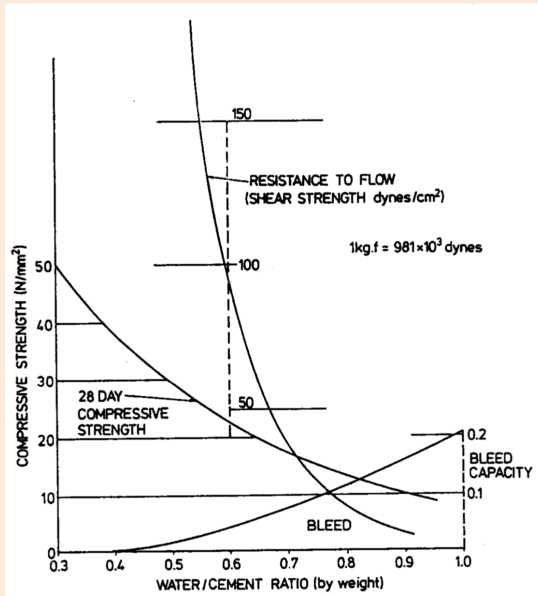
Type E Micropiles
Close up of Bit (Injection-Bore Threaded Bar)

2.2 Means, Methods and Materials

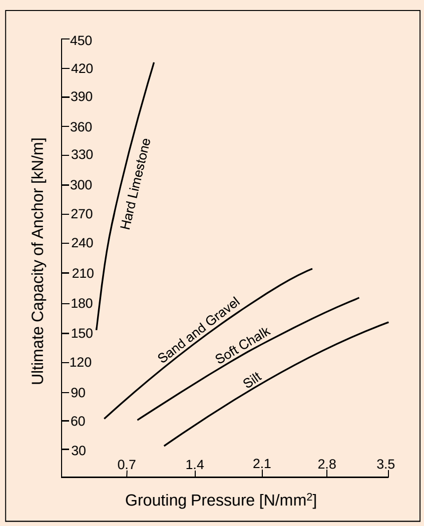
<u>Typical Grouting Characteristics</u>

- Neat cement grouts with water/cement ratios of 0.40 to 0.50
- Potable water used to reduce corrosion potential
- Type I/II cement (ASTM C150/AASHTO M85), in bag or bulk form
- Additives to improve pumpability in special cases
- Compressive strengths of 28 to 35 MPa (4 to 5 ksi)

Basics: Design of Neat Cement Grout



Relationship of Geotechnical Bond Value to Grouting Pressure



Influence of Grouting Pressure on Ultimate Load Holding Capacity

Grouting Equipment

- Mixers
  - High-speed, high-shear colloidal mixers essential
  - Low-speed, low-energy mixers (paddle mixers) are occasionally still used, but should not be
- Pumps
  - Constant pressure, rotary-screw type pumps (Moyno)
  - Fluctuating pressure piston or ram pumps
- Agitation Tanks
- Combined Units
- Batching and Injection Monitoring Equipment

Keys to Good Grouting

Grout Batching

- Water added to mixer using calibrated tank or flowmeter
- Cement is batched by <u>weight</u>, either in bags or bulk from a silo
- Additives are proportioned in relation to weight of cement

Keys to Good Grouting

Grout Mixing

- Grout mixing sequence: water, cement, additives
- Grout colloidally mixed for a maximum of 2 minutes and then held in a paddle agitation tank until needed
- Safe workability time typically not in excess of 1 hour

Grout Monitoring

Electronic Pressure and Flow Recorder

Limiting Excessive Takes of Primary Grout

- Injecting excessive quantities may be dangerous as well as wasteful
- Remedies include:
  - changing the rheology of the primary grout (e.g. add sand; reduce water/cement ratio; use appropriate additives)
  - changing the hydration characteristics of the primary grout (e.g. use accelerator)
  - in extreme conditions consider pretreatment of the entire area with an economic controllable grout (e.g. low mobility grout/concrete)

2.3 Grouting Quality Assurance and Quality Control (QA/QC)

- Critical importance
- Plans and specification development stage through final construction
  - Implementation of all requirements
  - Enforcement of qualifications
  - Submittal reviews
  - Installation

Site Organization and Leadership

"Mission Control"

Preproduction Testing

Maintaining Good Photographic Records in Real Time

Construction Monitoring

Grouting – Mixing and Pumping

- Ensure continuous grout placement
- Ensure cement is colloidally mixed and grout is continuously agitated
- Prevent presence of air in the grout lines
- Do not draw down the level of grout in the agitation tank below the crown of the exit pipe
- Ensure exclusion of foreign matter during grout placement

Construction Monitoring

Grouting – Placement

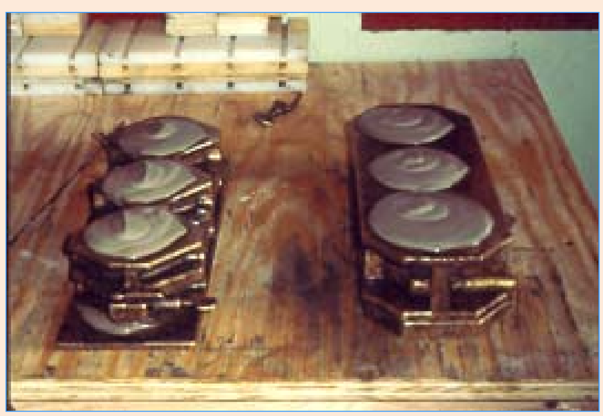
- Prevent heaving or ground distress
- Prevent soil in bottom of hole from blowing in
- Grout as soon as possible after drilling the bond zone
- Use tremie to ensure complete filling of hole
- Tie tremie tube loose enough for removal during/or after tremie grouting

Construction Monitoring

Grouting – Placement (continued)

- Observe suitable grout return
- Maintain a positive head at the grout holding tank
- Measure grout pressures close to the point of injection to account for line losses
- Monitor grout pressures and volumes throughout both tremie grouting and pressure grouting (if used) processes
- Typical post-grouting pressures are typically 200-600 psi
  - safety issue

Grout Testing



Cubes – practically useless as a routine QA/QC tool

Real time testing of fluid grout properties is far superior

– Baroid Mud Balance (SG)

– Marsh Cone (Fluidity)

3. Storage, Handling and Placement of Reinforcement

Types

- Reinforcing steel bars (rebar)
- Continuous-thread solid steel bars
- Continuous-thread hollow-core steel bars (injection bore)
- Steel pipe casing
- Composite reinforcement

- Placed either before or after initial tremie grouting (but always before the temporary casing is withdrawn)
- Reinforcement must be clean of surface soil and mud
- Centralizers used to maintain the specified grout cover

Handling and Storage

- Store in a protected location
- Inspect steel when delivered to site
- Reject steel that exhibits flaky corrosion or pitting
- Extra care with corrugated protected/epoxy-coated bars

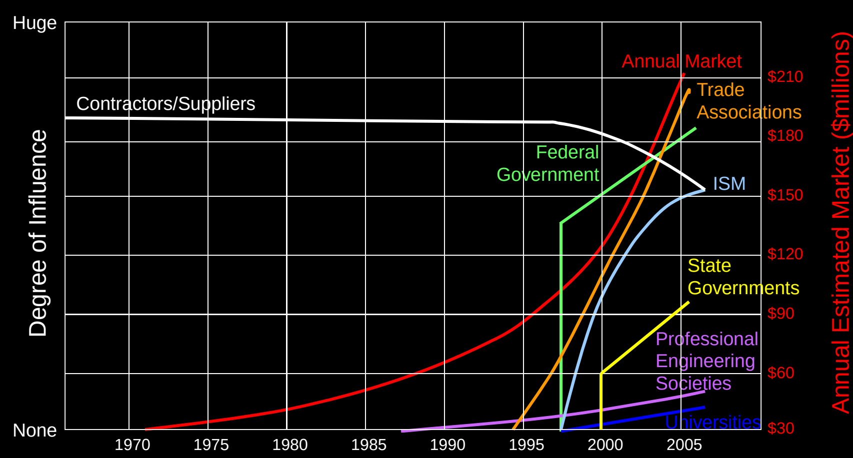
Installation

- Install either before or after initial grout placement but before temporary casing (if used) is withdrawn
- Record the total pile length and bond zone length
- Insert to the prescribed length without the use of force
- Do not damage corrosion protection or centralizers during installation

Installation (continued)

- Ensure reinforcement is clean of any surface soil, oil, mud etc.
- Check attachment and intervals (typically 2.5 to 3 meters) of centralizers and spacers
- Center reinforcement in borehole
- Ensure full engagement of successive bar or pipe sections

4. Growth of the Micropile Market in the U.S.



5. Final Comments

"Profile of a Driller"

"Drillers are as diverse a group of people as the industry in which they work. Every drilling operation is different and requires a highly skilled person to ensure that the drilling process is successful."

Australian Drilling Industry Technical Training Committee Ltd. (1997)

Areas of Concern

- Micropiles in karst. (Owners must recognize need for pregrouting and/or remedial grouting.)
- Decline in standards (“familiarity breeds contempt”).
- Continued support for DFI, ADSC and ISM micropile activities.

Dedicated to the Vision of
Dr. Fernando Lizzi
(1914-2003)

The Godfather of Micropiles