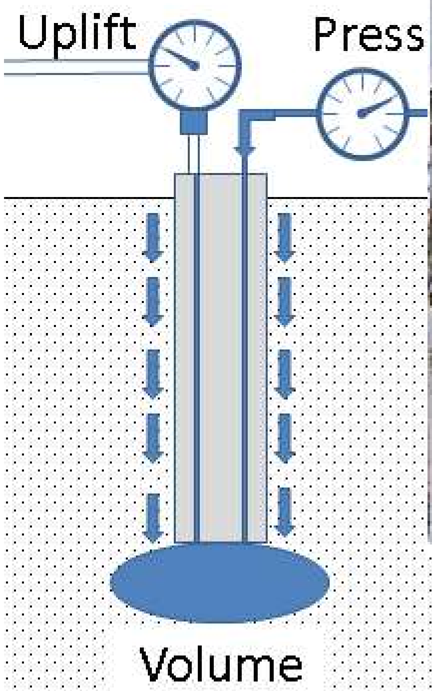
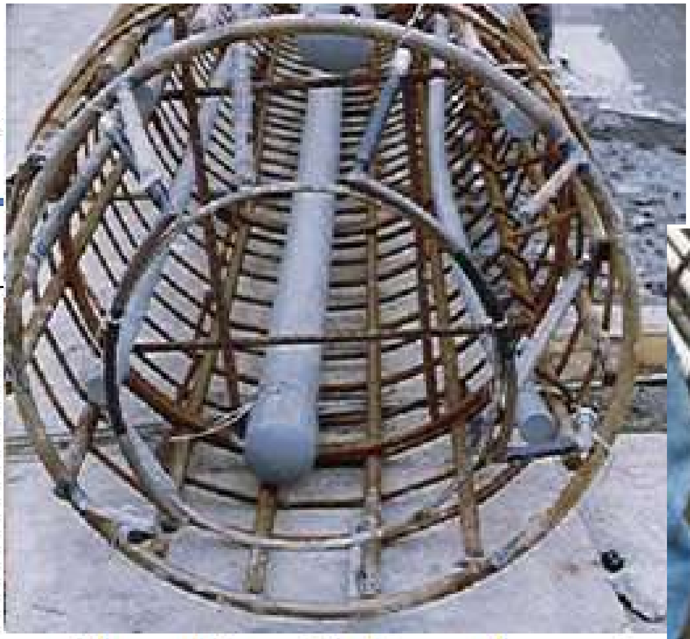
Load and Resistance Factor Design (LRFD) Resistance Factors for Tip Grouted Drilled Shafts





BDV25 TWO 977-37

GRIP 2017

USF UNIVERSITY OF SOUTH FLORIDA

Civil & Environmental Engineering

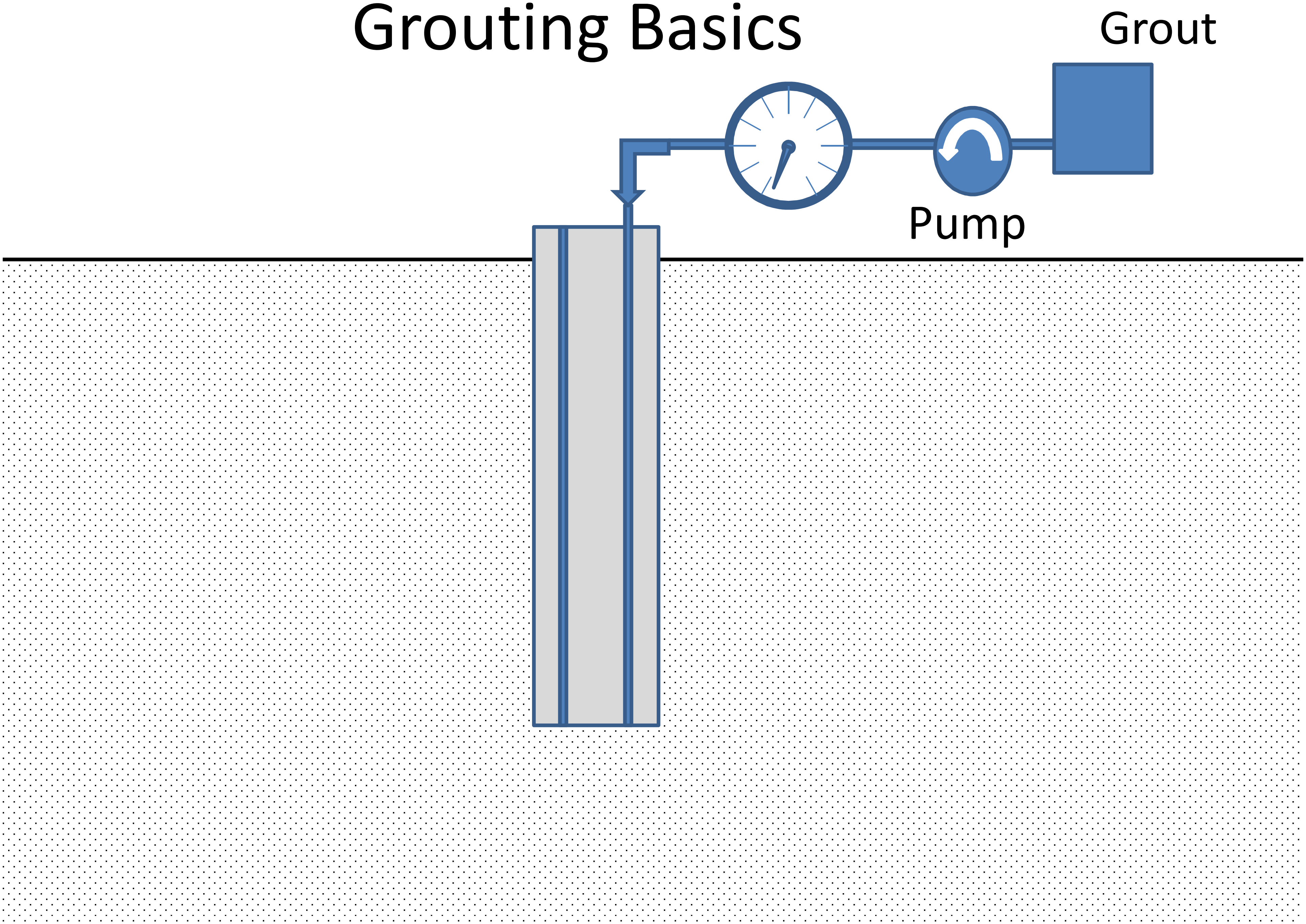
Outline

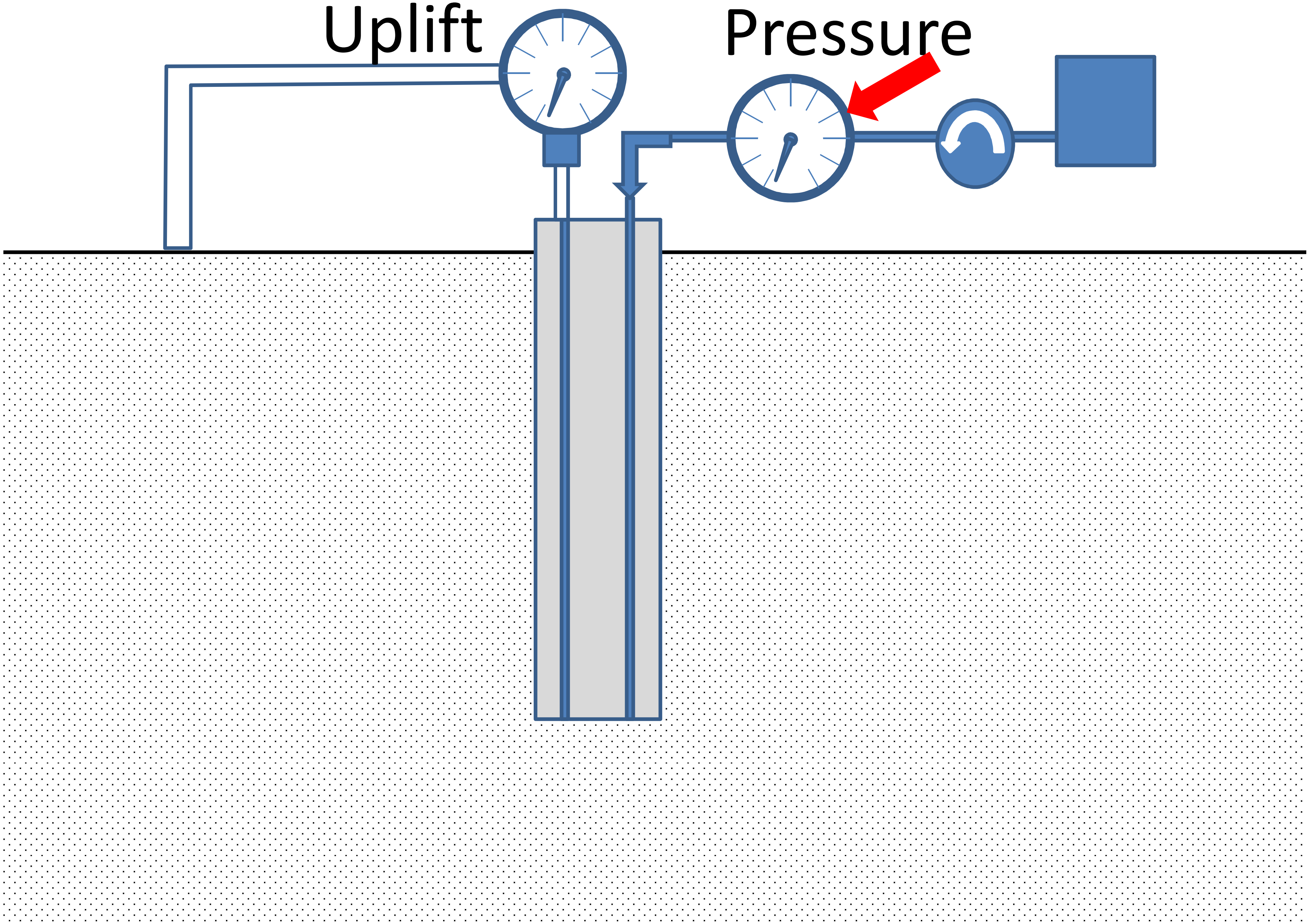
- Problem Statement
- Background
  - Grouting Basics
  - Grouting Systems
  - Grouting Methods
- Expected Grouting Performance
- Design Methods
- Resistance Factors
- Tasks
- Schedule

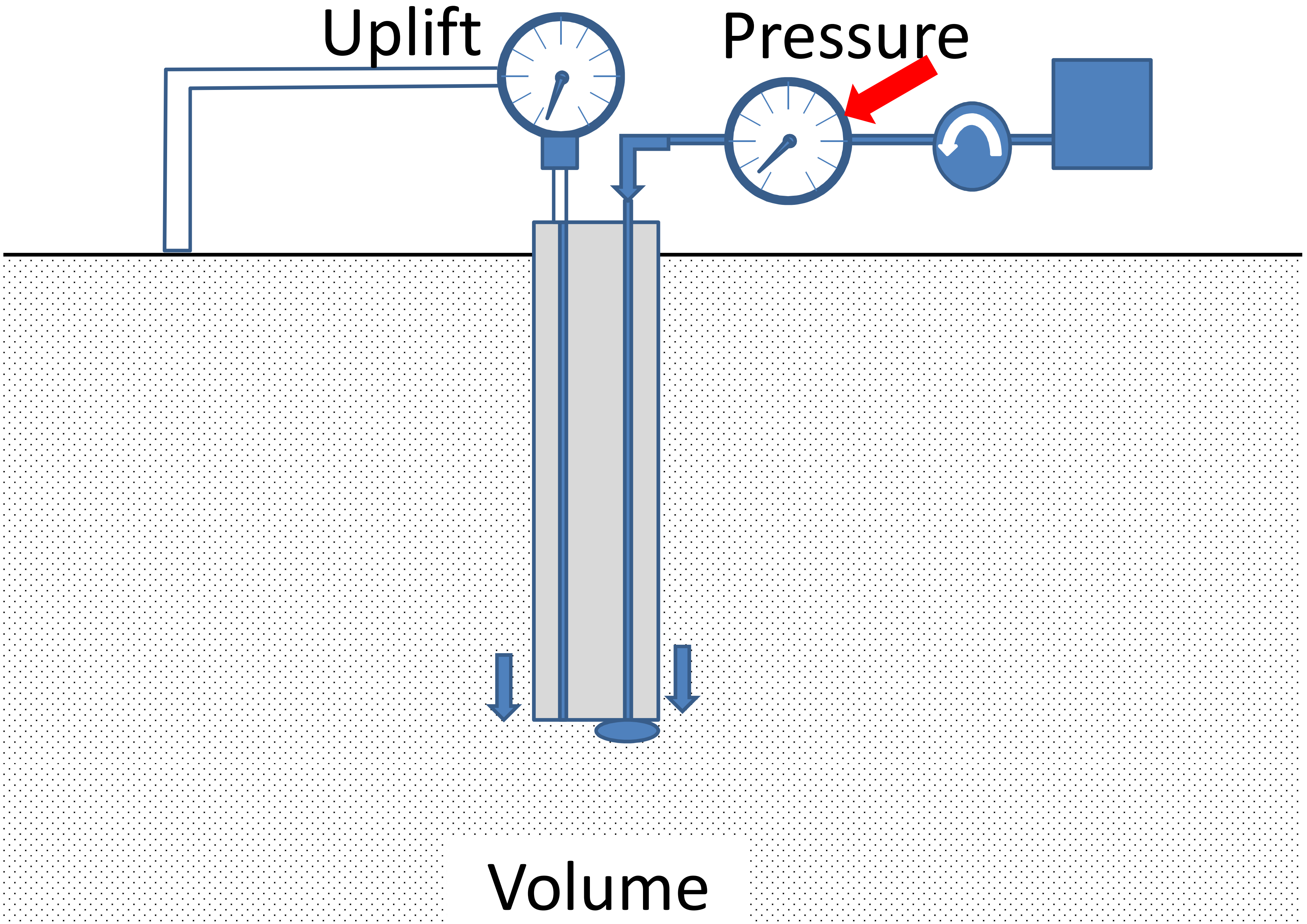
Problem Statement

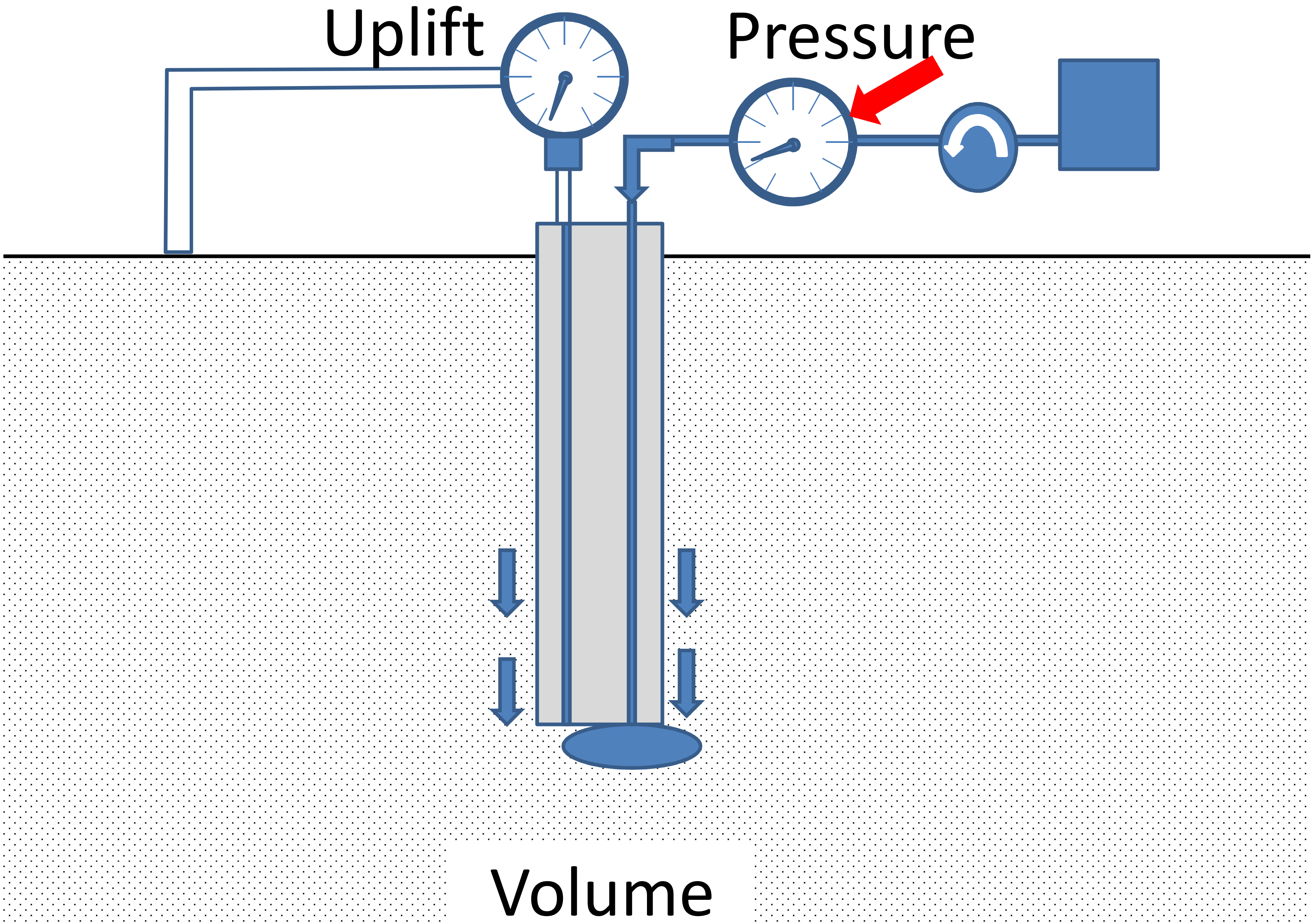
- Like all capacity prediction methods, the post-grouted end bearing of drilled shafts has inherent uncertainty.
- Both the design and construction practices are affected
- No resistance factors (or safety factors) are in place to moderate the uncertainty associated with varying design or grouting methods

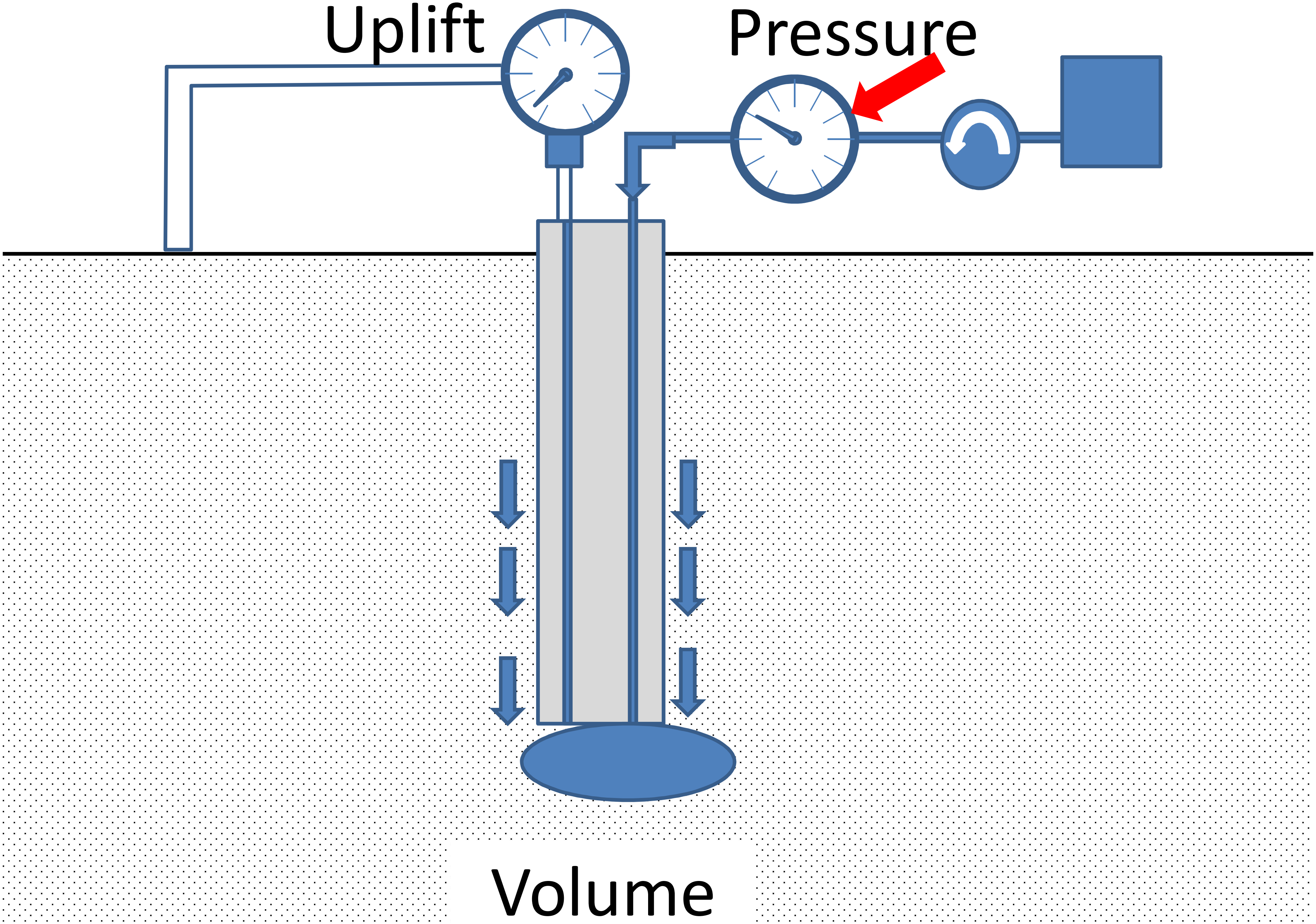
Grouting Basics



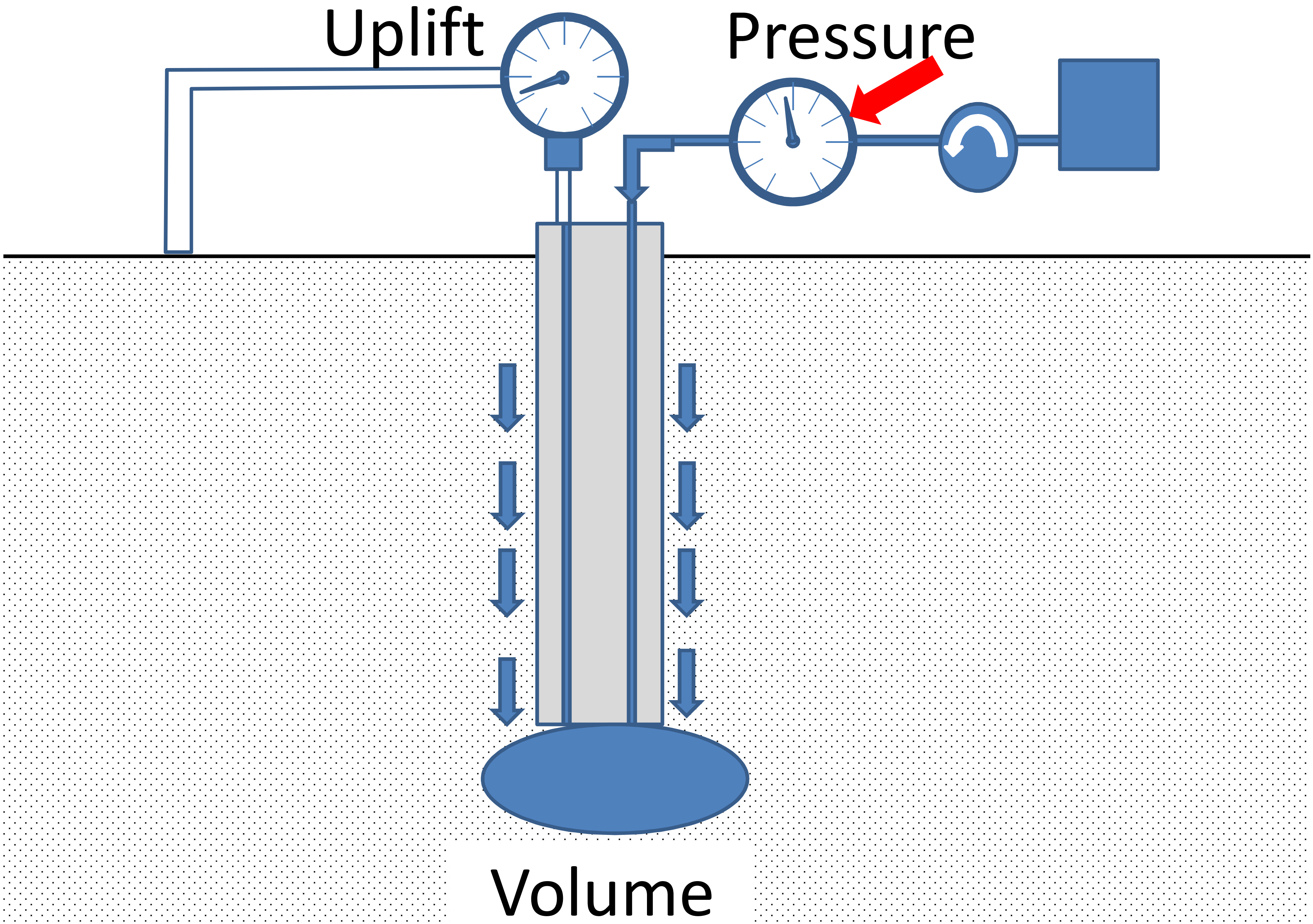

Uplift
Pressure

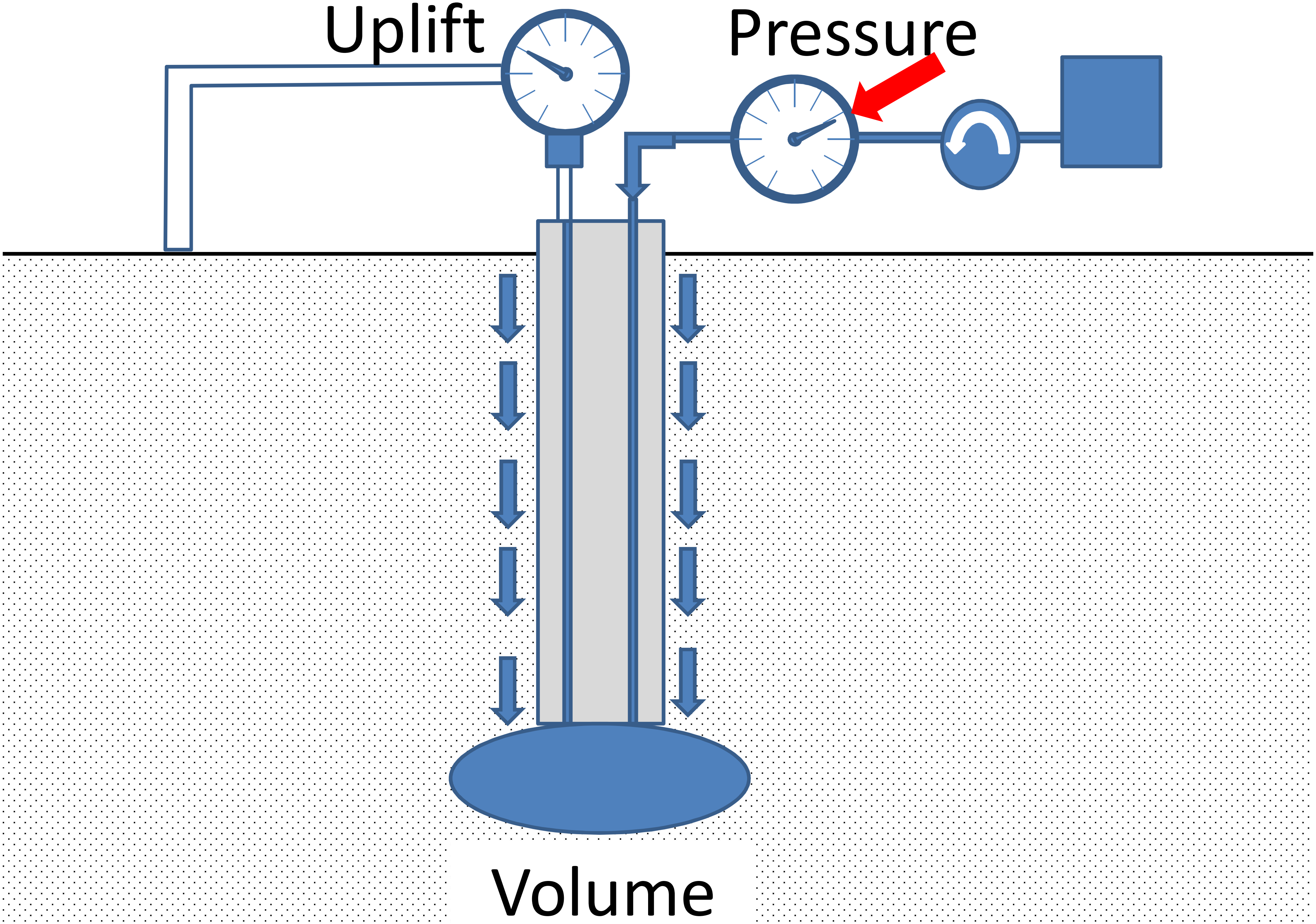

Uplift
Pressure
Volume


Uplift
Pressure
Volume

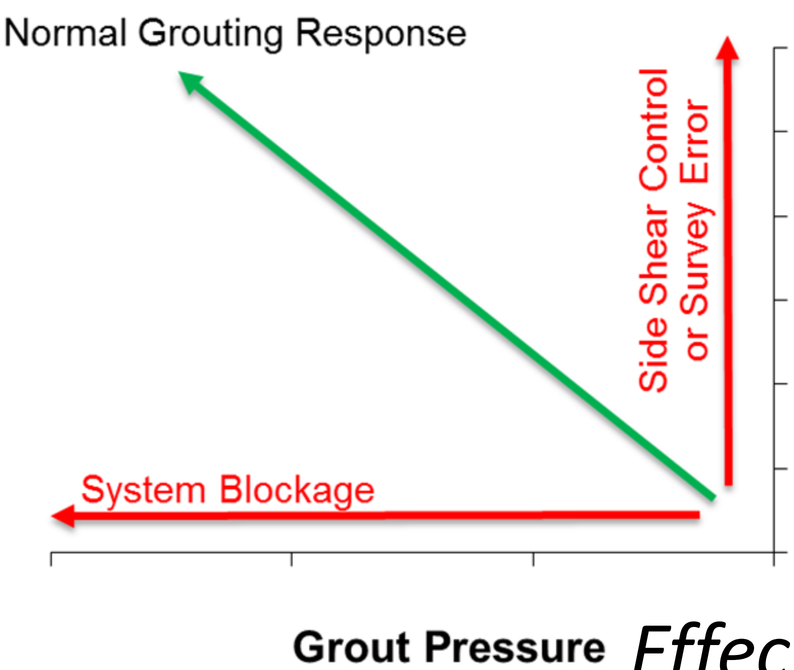


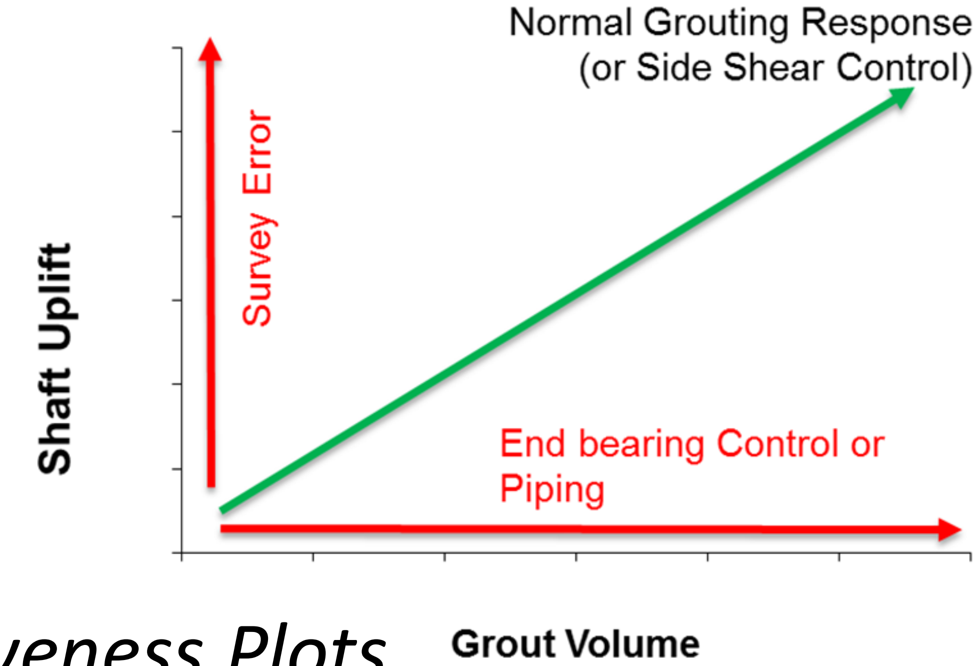
Uplift
Pressure
Volume


Uplift
Pressure
Volume


Uplift
Pressure
Volume

Effectiveness Plots

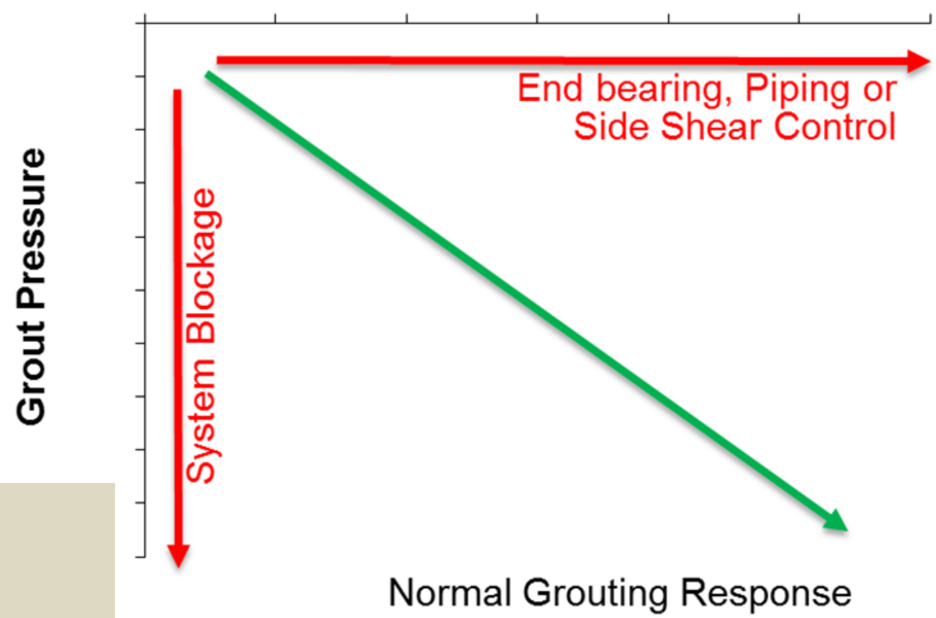




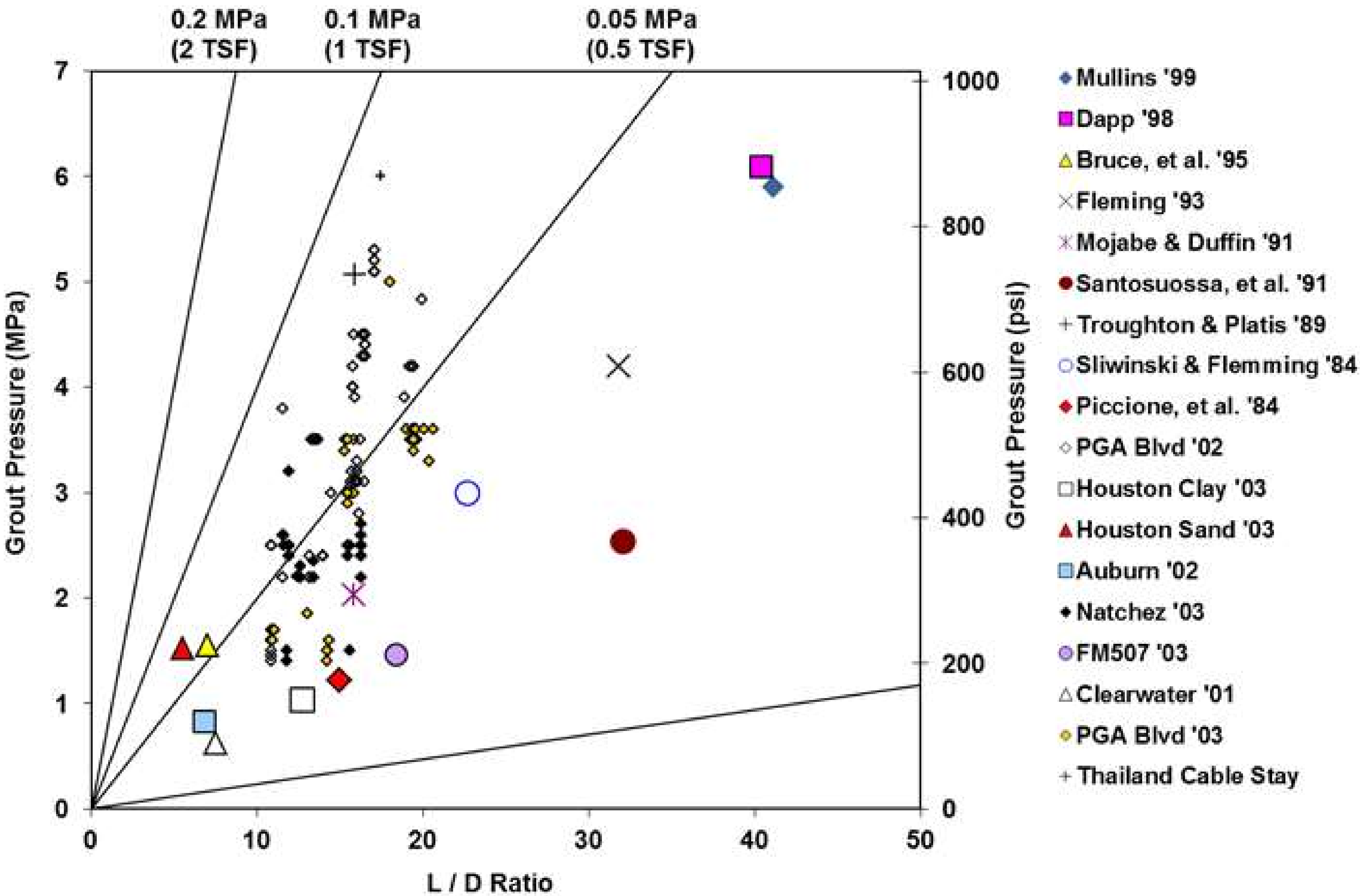
NOTE:

(1) All graphs should demonstrate a diagonal trend away from the center.

(2) If any one of the graphs demonstrates a horizontal or vertical trend, the post grouting process has become ineffective for one of the reasons shown



Expected Results


0.2 MPa
(2 TSF)
0.1 MPa
(1 TSF)
0.05 MPa
(0.5 TSF)
Grout Pressure (MPa)
Grout Pressure (psi)
L / D Ratio
0
1
2
3
4
5
6
7
0
10
20
30
40
50
0
200
400
600
800
1000
Mullins '99
Dapp '98
Bruce, et al. '95
Fleming '93
Mojabe & Duffin '91
Santosuossa, et al. '91
Troughton & Platis '89
Sliwinski & Flemming '84
Piccione, et al. '84
PGA Blvd '02
Houston Clay '03
Houston Sand '03
Auburn '02
Natchez '03
FM507 '03
Clearwater '01
PGA Blvd '03
Thailand Cable Stay

Grouting systems

Sutong (China)

Taipei 101 (Taiwan)

Flagler (Florida)

Sleeve Port (tube-a-manchette)

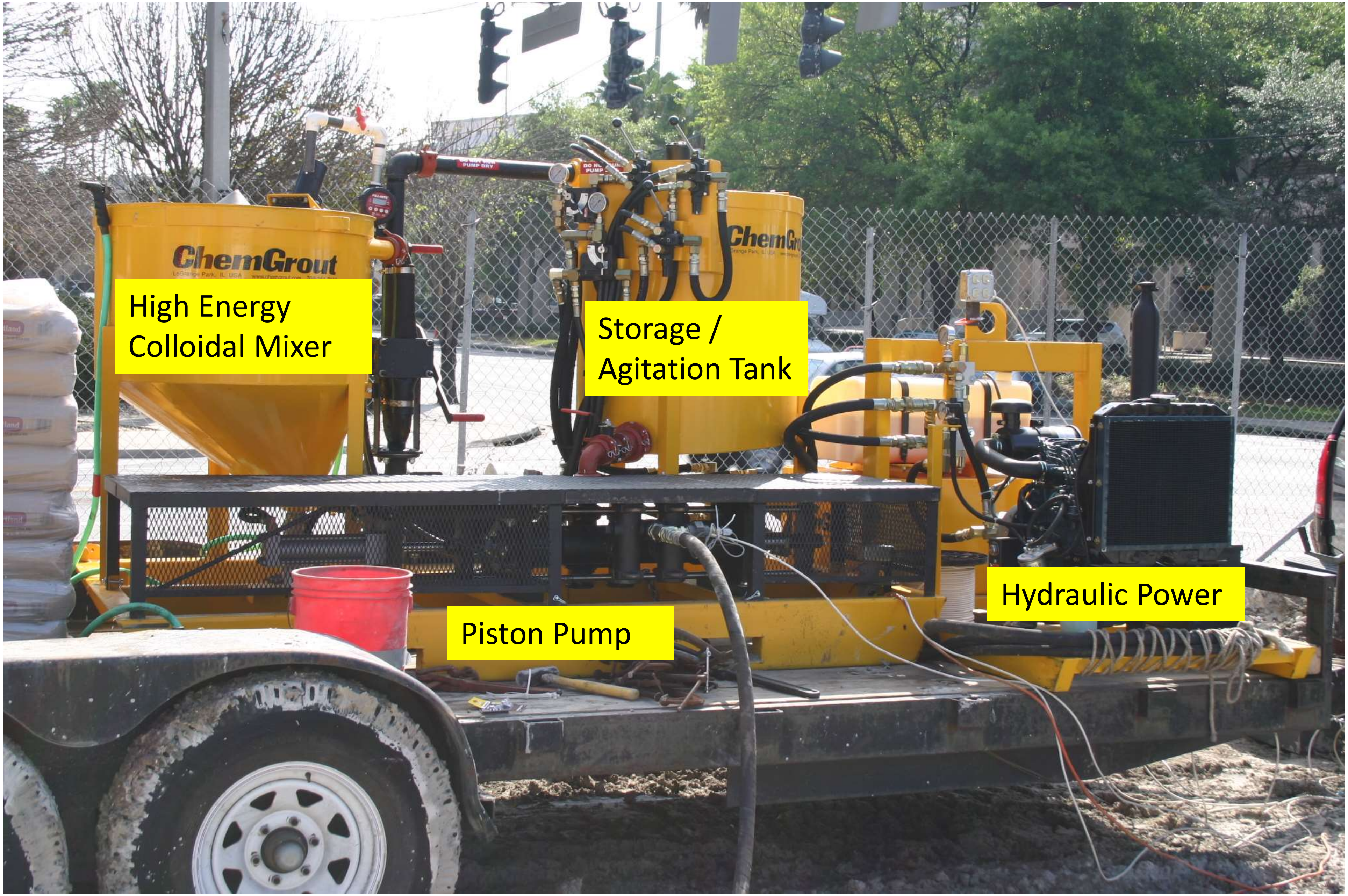
Grouting systems

Flat jack (open or closed)

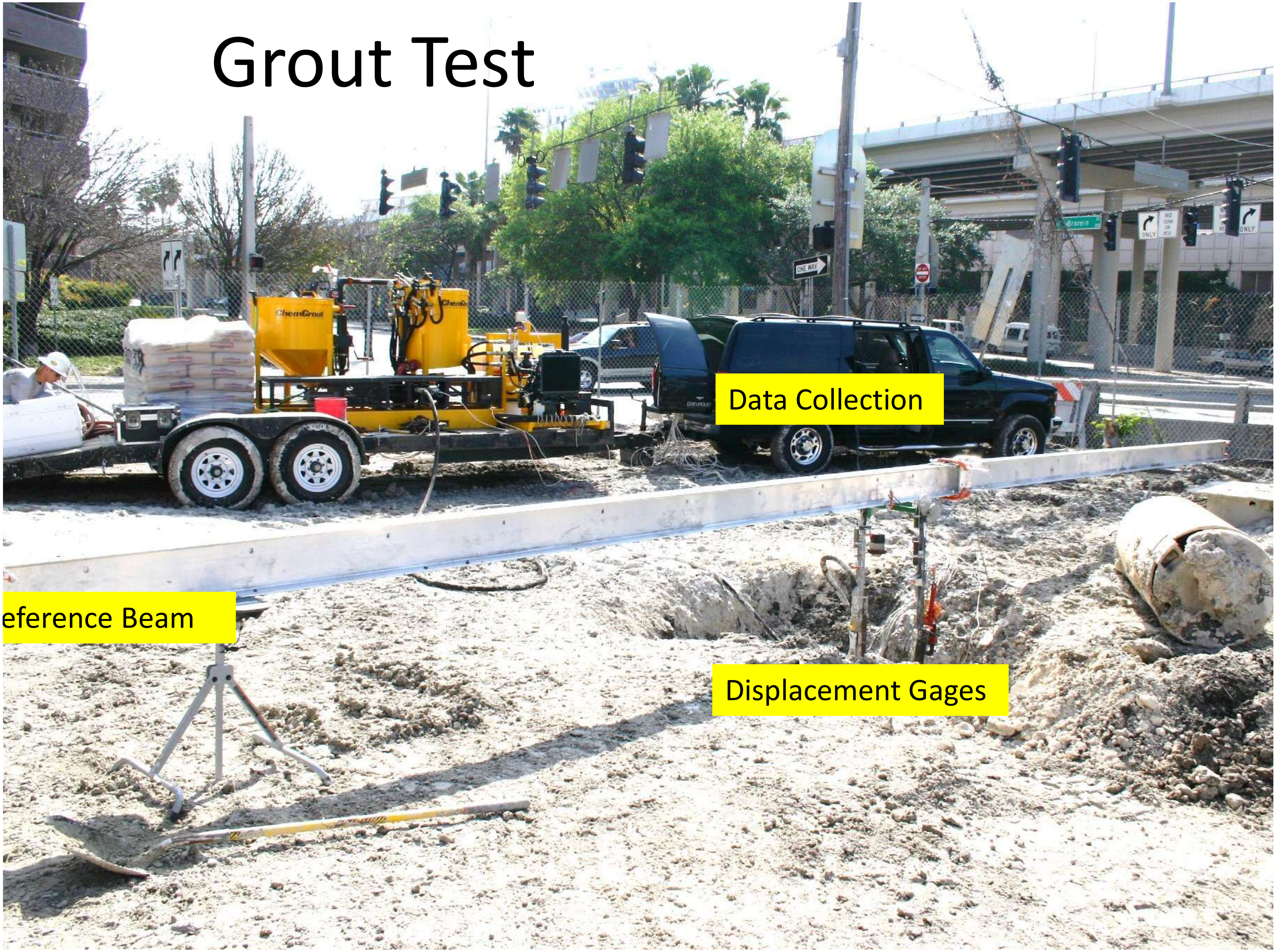
Grouting Method

- Attach distribution system to cage
- Construct shaft in normal fashion
- Flush grout distribution system (burst sleeve ports) before concrete has full strength
- Cure concrete
- Pump neat cement grout through lines demonstrating system is clear, close return valves and pump grout until design pressure is achieved
- Record: volume, pressure, uplift and strain at prescribed intervals (e.g. 10 data points up to design pressure)

Grout Mixer / Plant



Grout Test



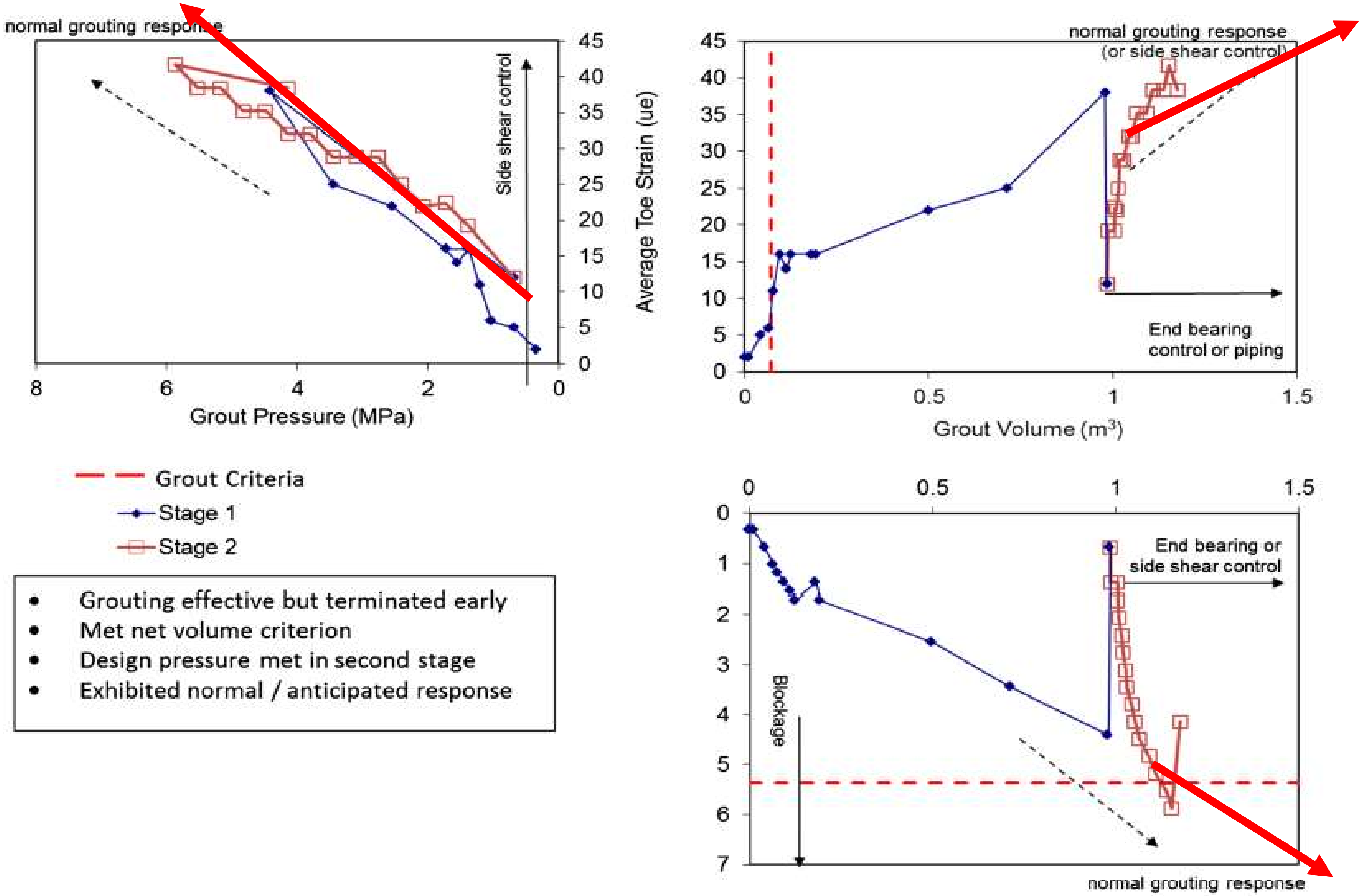
Flush with clean water


Grout return

Field Practice / Design Expectation

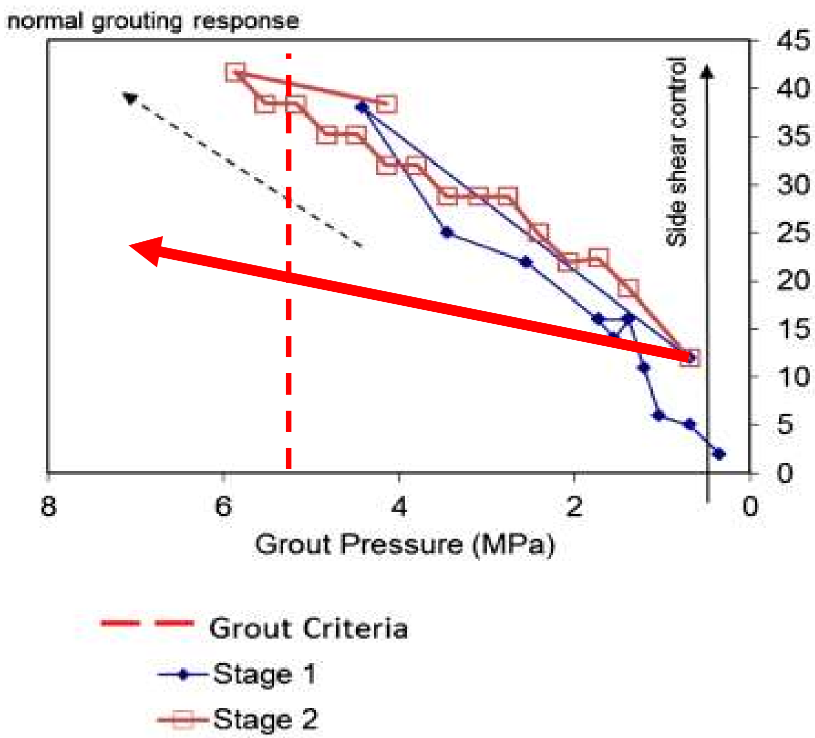
- Grout pressure is intended to create an expanding bulb of grout where pressure increases with size of bulb
- If pressure is not achieved, stage grouting is often suggested
- Stage grouting reduces the size of the active/liquid grout pressure area and does not continue to increase soil improvement
- Design methods implicitly assign capacity gains on a combination of increases in tip area and soil strength
- Designer must be aware of this global effect

Best Case Effect of Stage Grouting



- Grouting effective but terminated early
- Met net volume criterion
- Design pressure met in second stage
- Exhibited normal / anticipated response

Undesired Result of Stage Grouting



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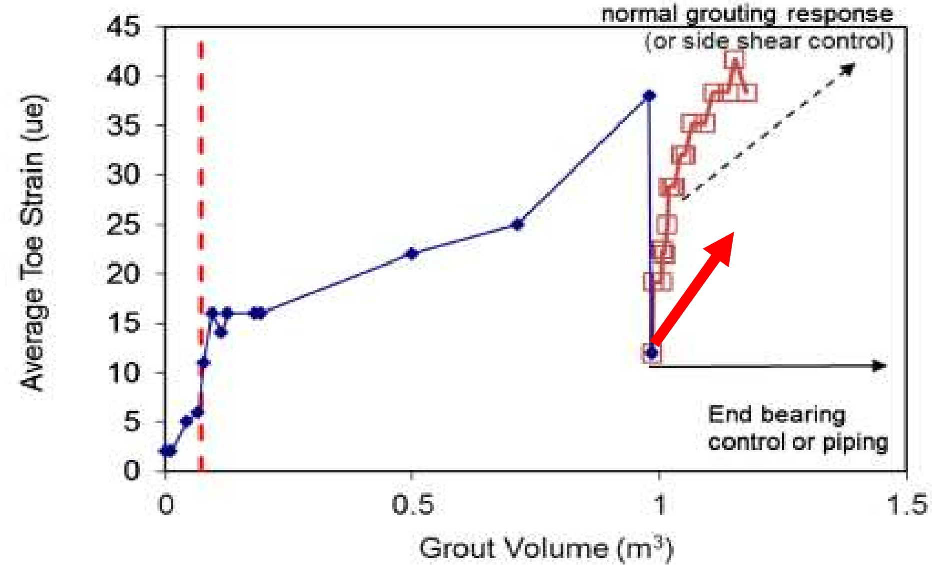
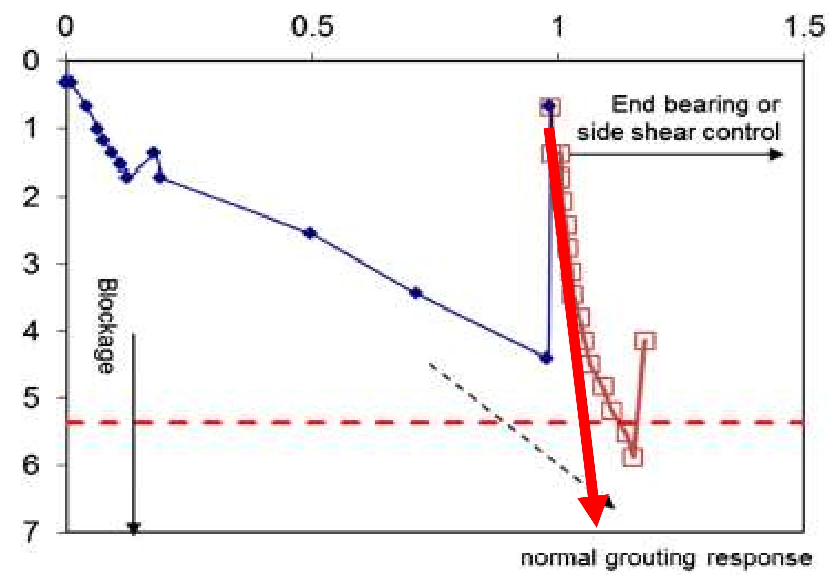




Design Methods

Three Basic Approaches

- Unit end bearing = Grout pressure
- Unit end bearing function of grout pressure and displacement
  - Single stage grouting *Mullins et al. 2006*
  - Multi-stage grouting *Dapp and Brown, 2010*

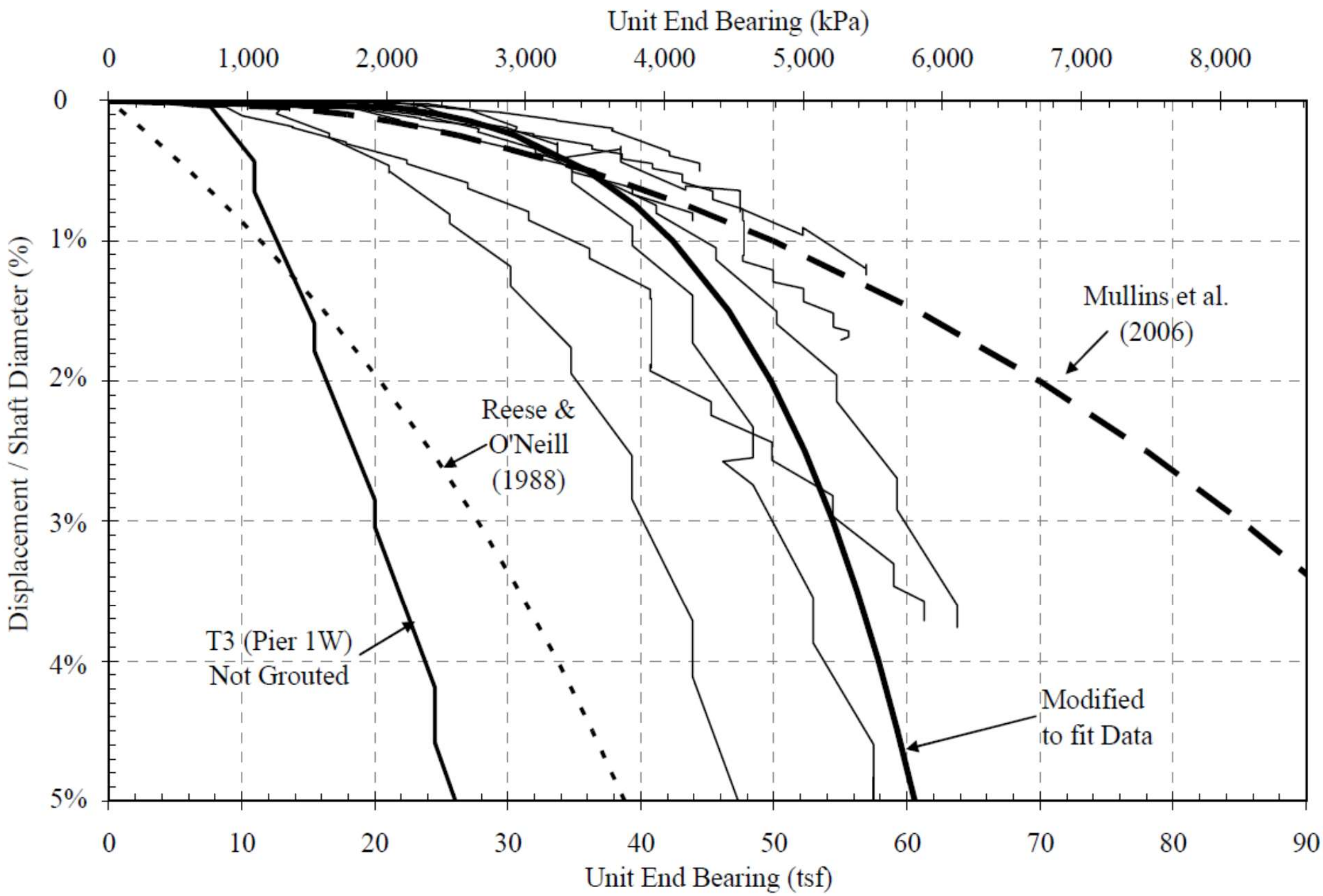
Design Methods

- q = grout pressure (conservative)
- q = $(0.713(GPI)(\%D^{0.364}) + \frac{\%D}{0.4(\%D)+3.0})$ 0.6N

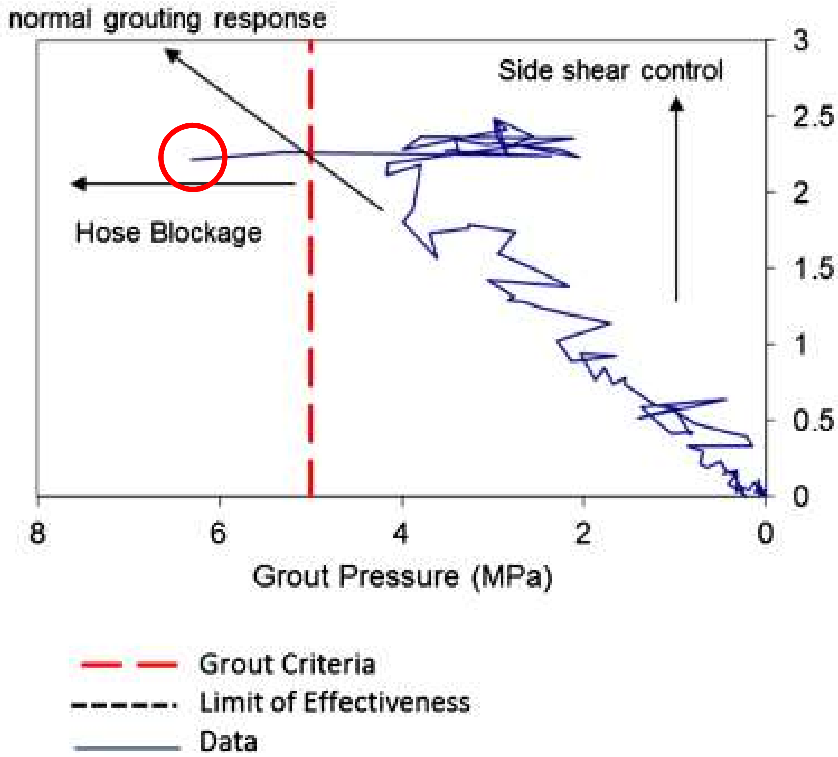
  Mullins et al. 2006
- q = $(0.713(GPI)(\%D^{0.2}) + \frac{\%D}{0.4(\%D)+6.0})$ 0.6N

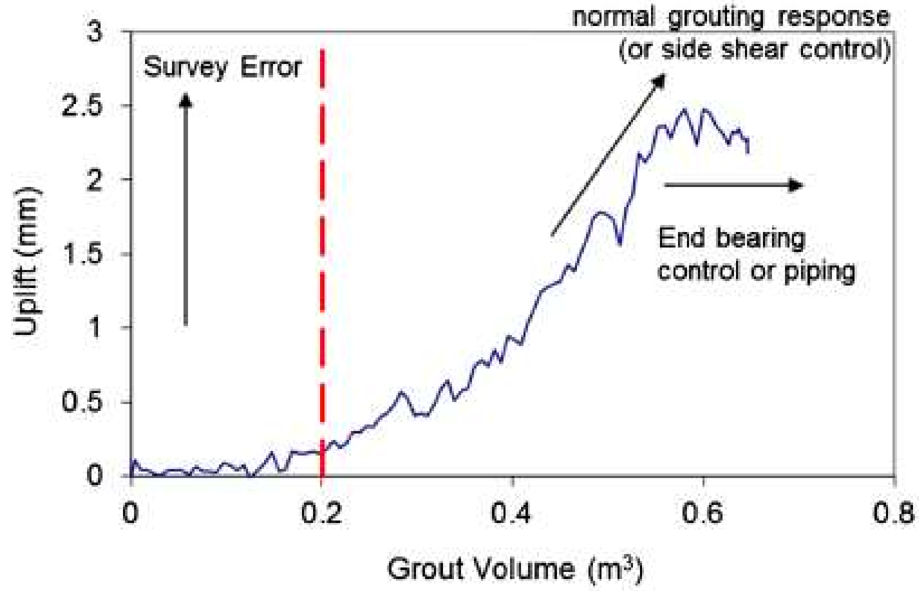
  Dapp and Brown 2010

Grouting Effectiveness or Design Method

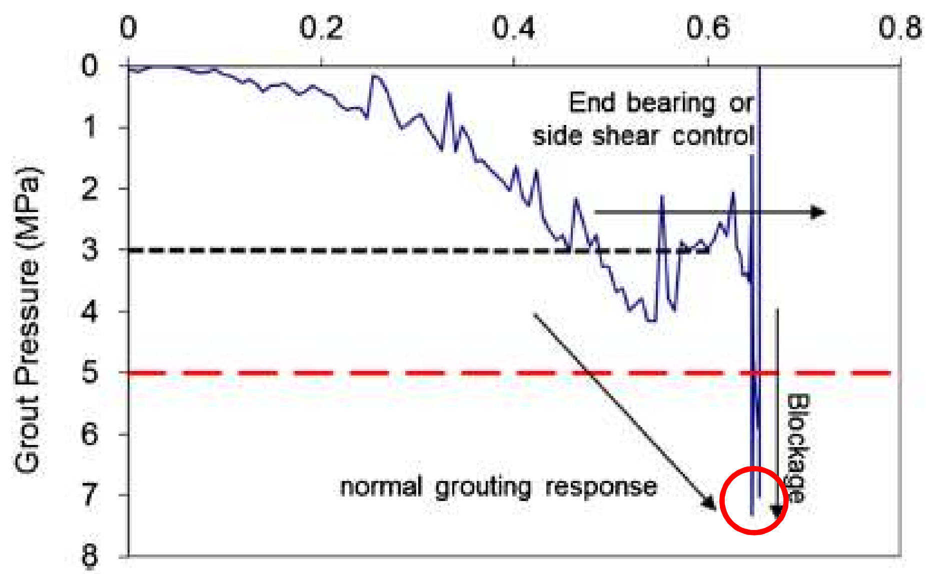


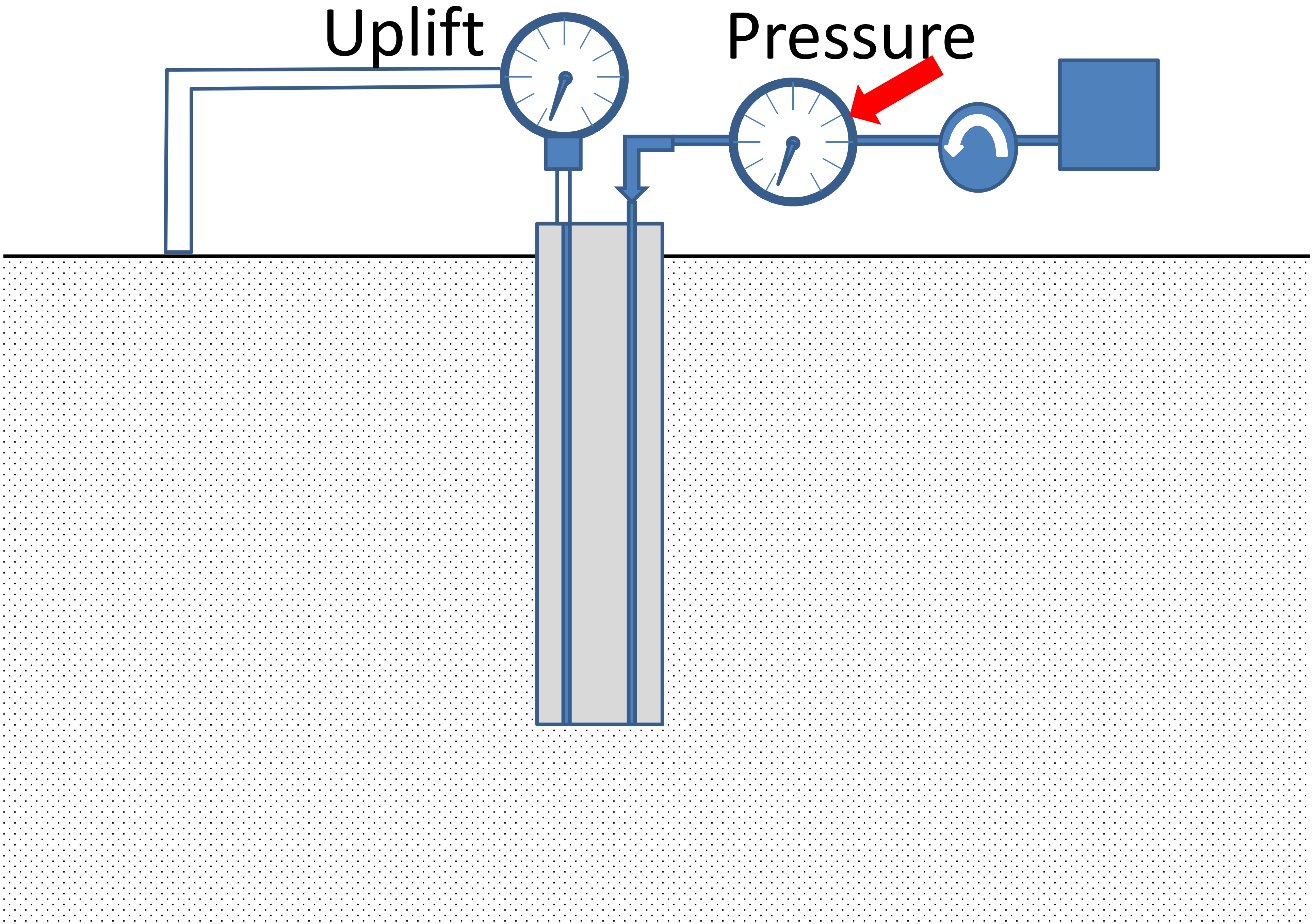
Grouting Effectiveness or Design Method

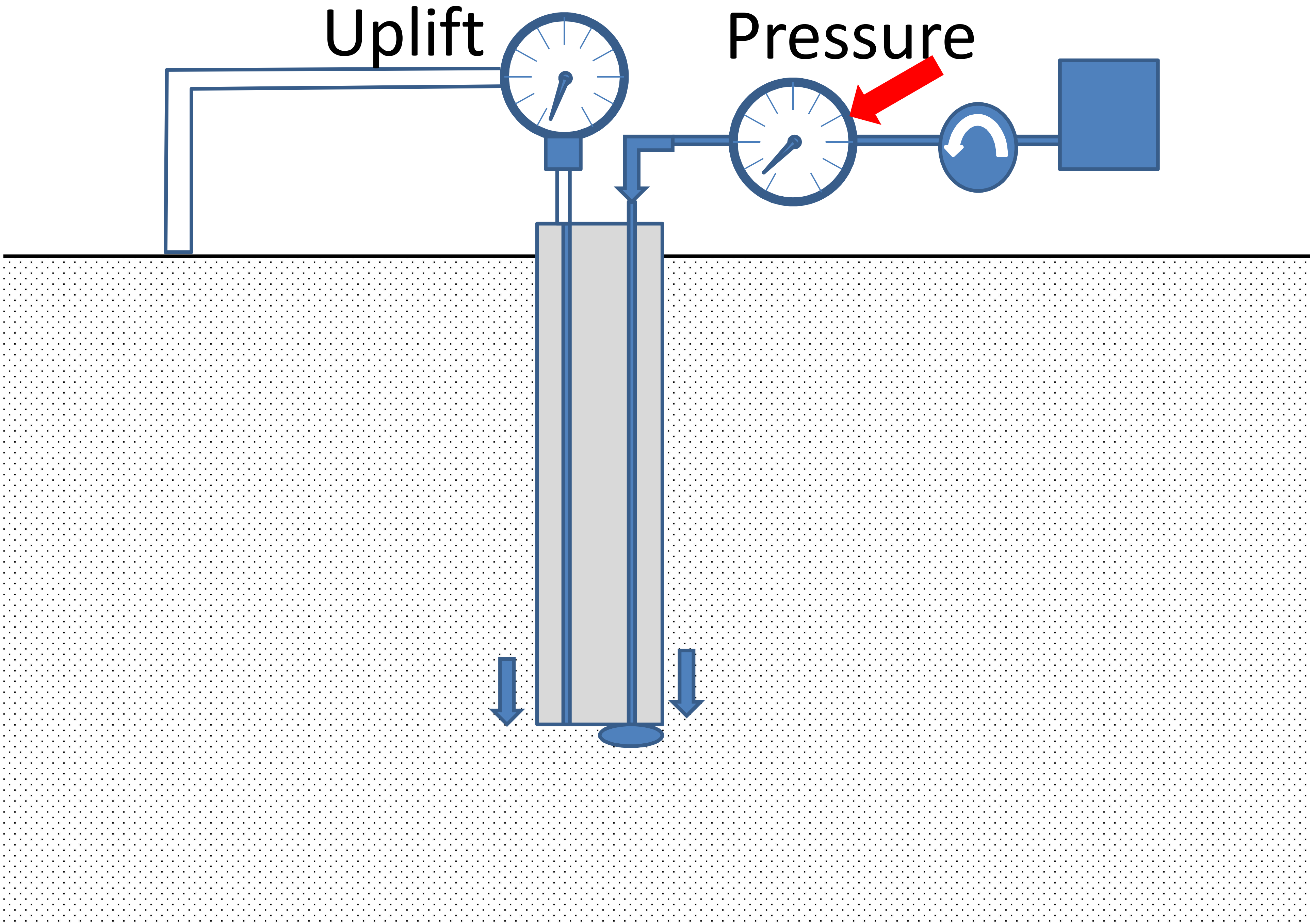


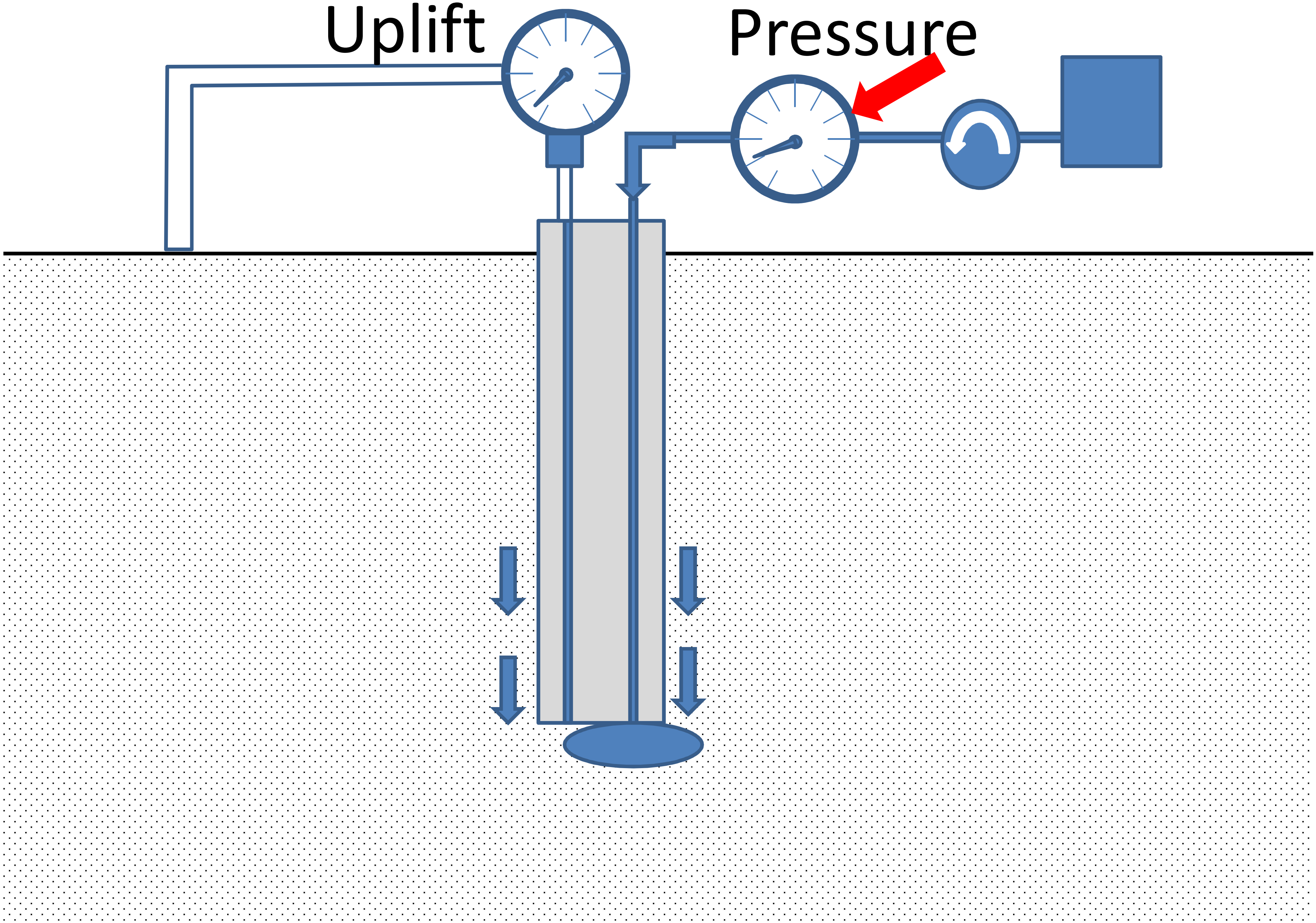


- Grouted normally up to 4MPa
- Exceeded net volume criterion
- Exhibited end bearing failure
- Followed by system blockage
- Met both pressure and volume criterion, but not actually
- Effectively ended at 3MPa

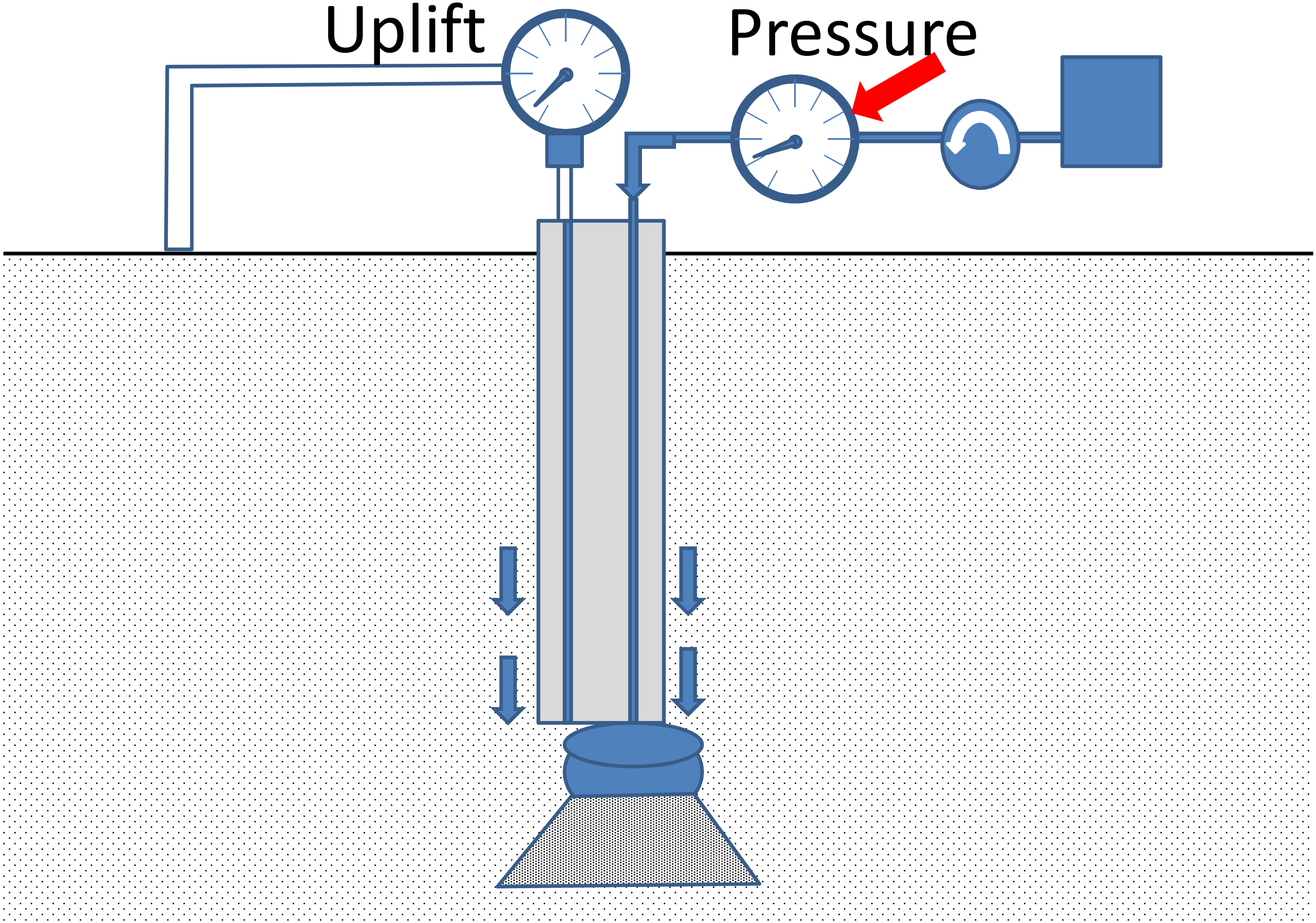


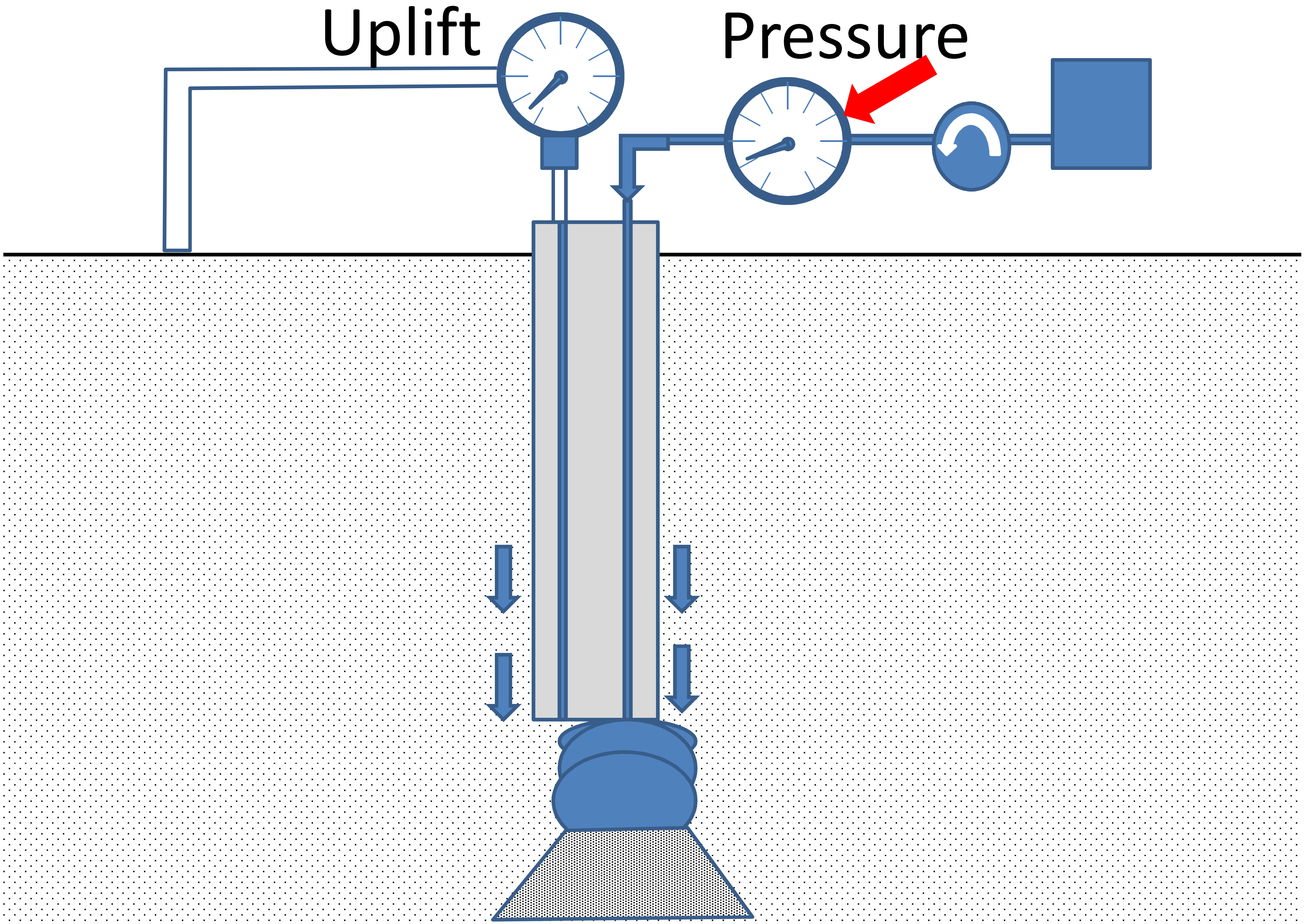

Uplift
Pressure

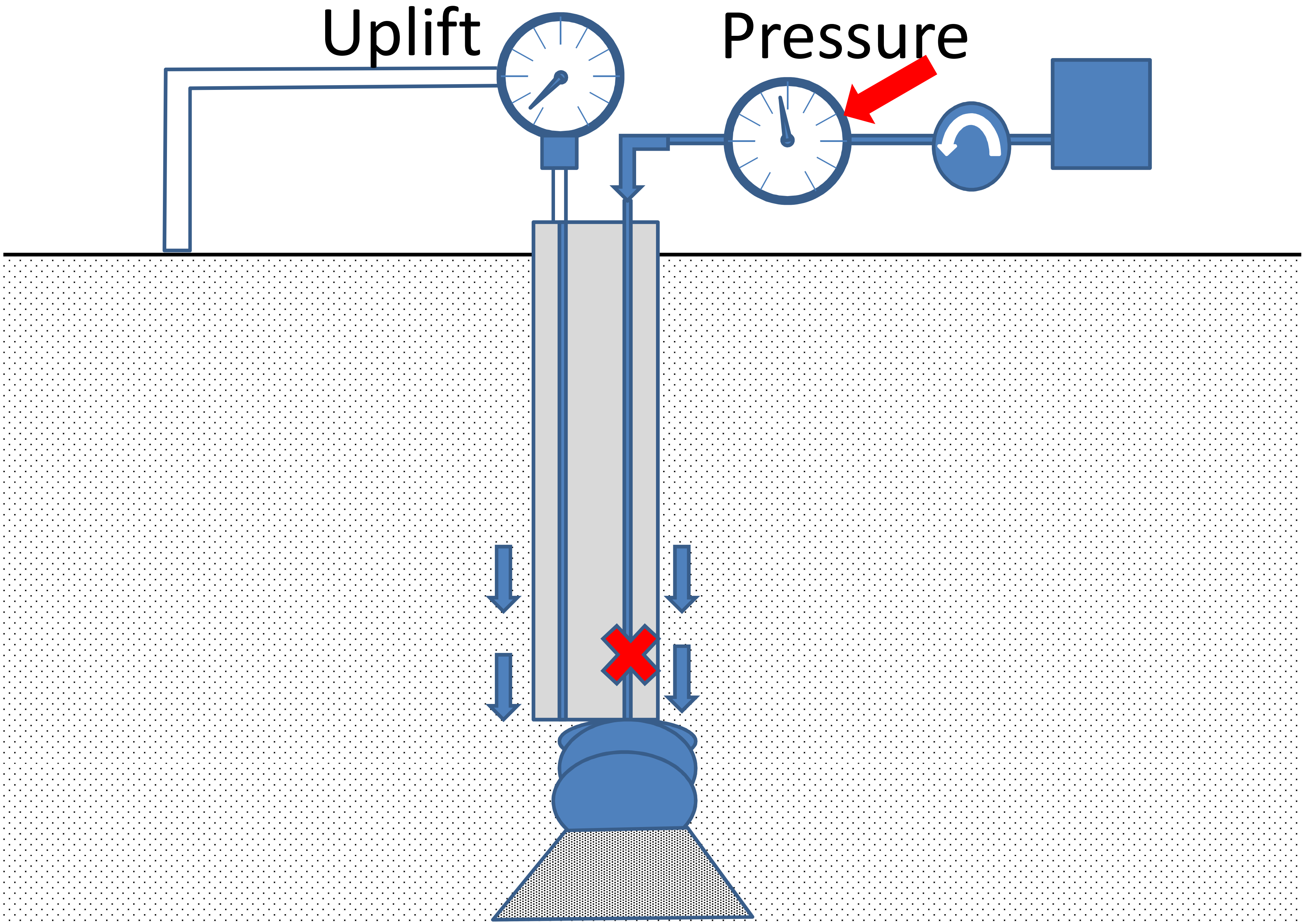

Uplift
Pressure

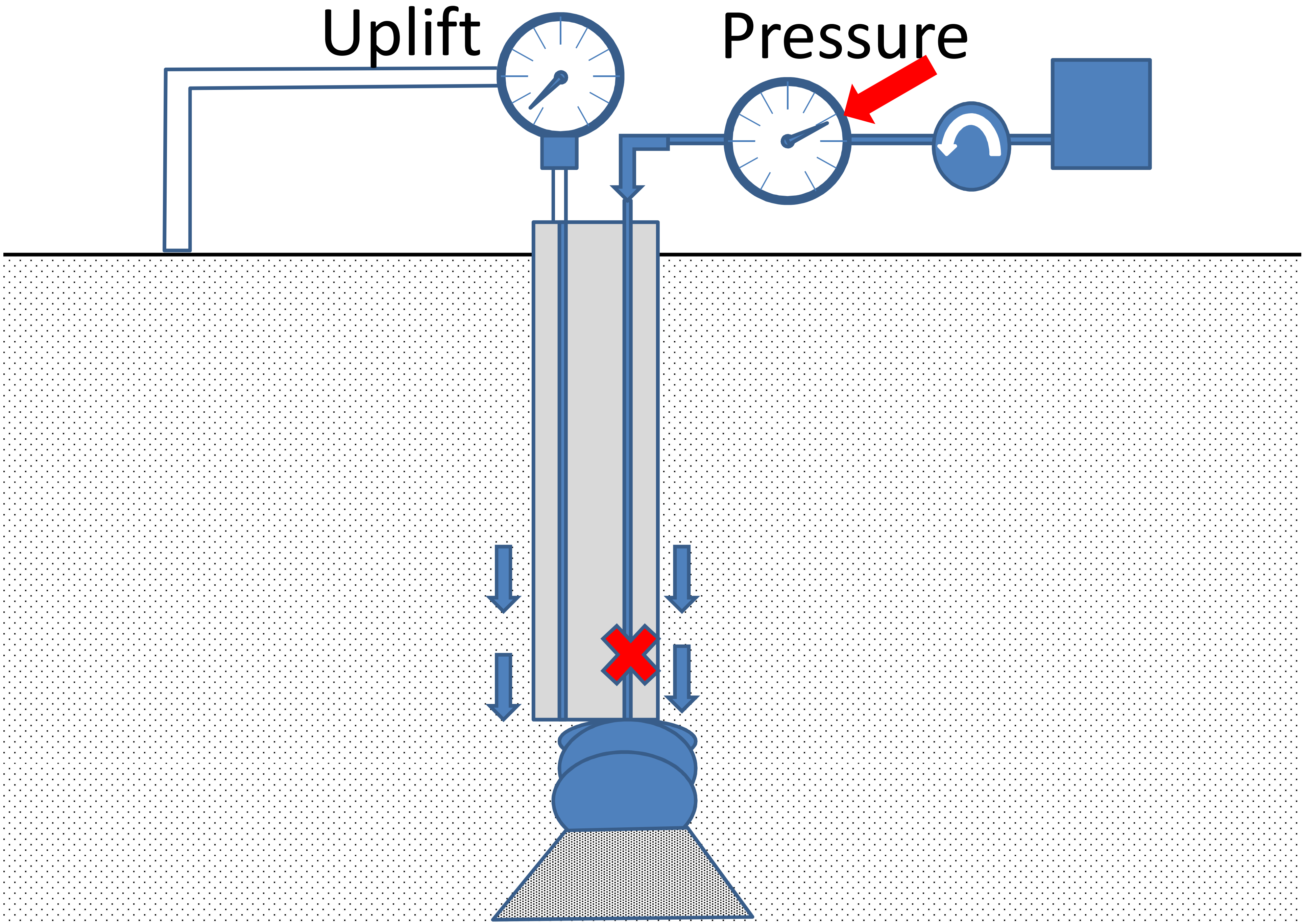


Uplift
Pressure

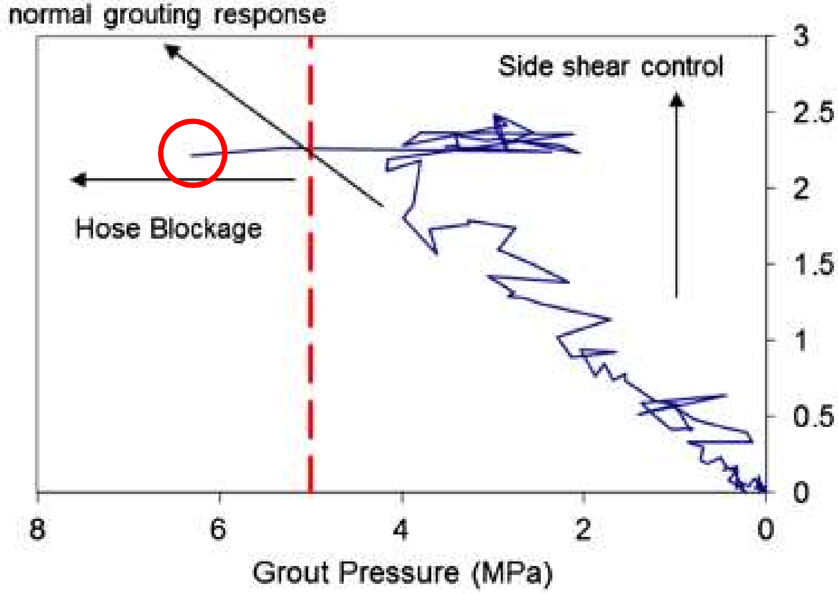

Uplift
Pressure

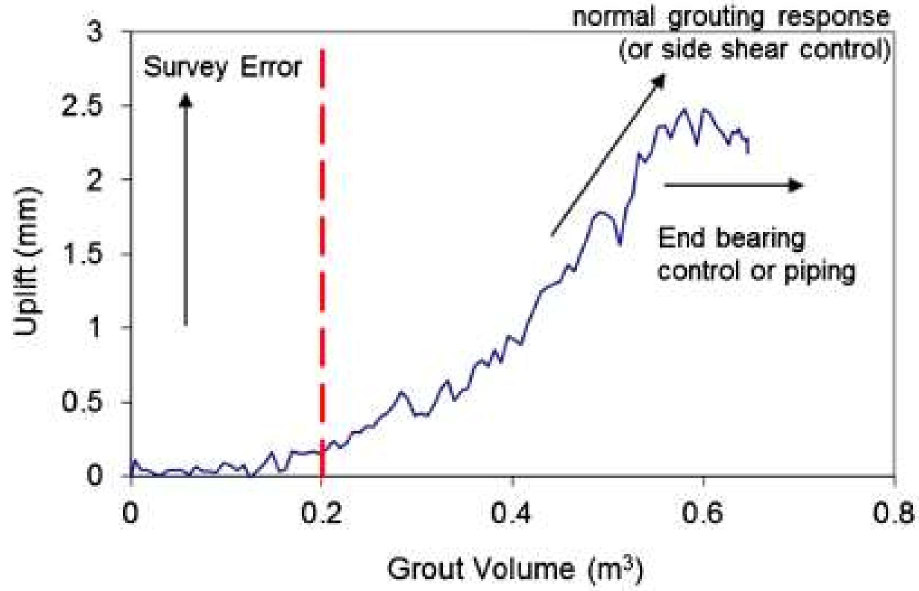

Uplift
Pressure


Uplift
Pressure


Uplift
Pressure

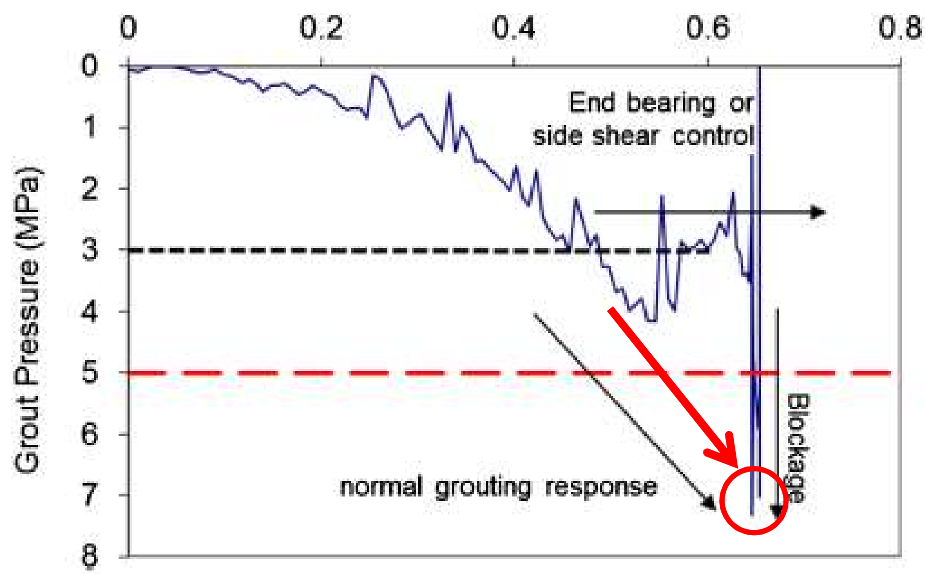
Grouting Effectiveness or Design Method





Grout Criteria
Limit of Effectiveness
Data

- Grouted normally up to 4MPa
- Exceeded net volume criterion
- Exhibited end bearing failure
- Followed by system blockage
- Met both pressure and volume criterion, but not actually
- Effectively ended at 3MPa



Factors Affecting Resistance Factor (measured/predicted)

- Design Method
  - Grout pressure / side shear prediction
  - End bearing prediction
- Displacement
  - Not a single capacity
  - Davisson method not applicable
- Field Method
  - Single or multi stage
- Grouting Effectiveness
  - Effectiveness plot verification
- Frequency of Load Testing

Soils and Foundations Handbook

“Resistance factors and associated design methods for geotechnical resistance of drilled shafts are in SDG Table 3.6.3-1 [Table 2.3]. *It is implicitly shown in the table that the resistance factors for drilled* ***shafts tipped in sand or clay*** *are based on* ***side shear*** *design methods* ***only*** *(i.e. FHWA alpha method in clay and FHWA beta method in sand).”*

Soils and Foundations Handbook

*“**In sand, drilled shafts with pressure grouted tips should be considered**. Pressure grouted tips are most effective in loose to medium dense sands. Guidance for the design of drilled shafts with pressure grouted tips may be found in Appendix D and in Reference 9.”*

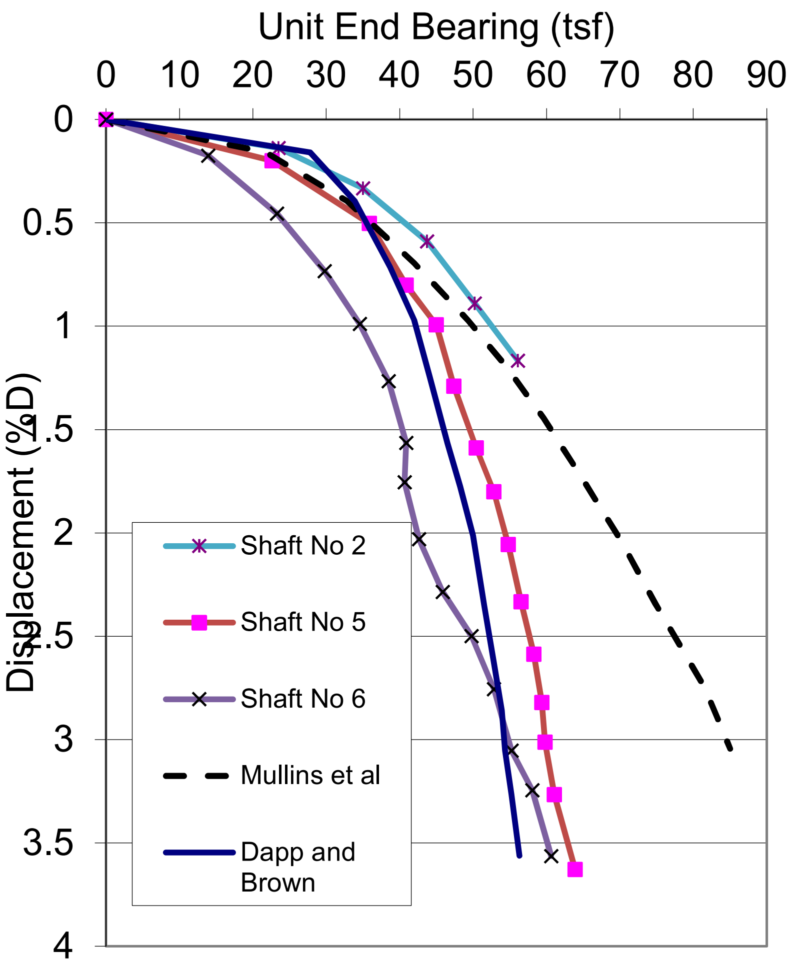
No Resistance Factor is directly associated with PG shafts; rather that from the load test method is used.

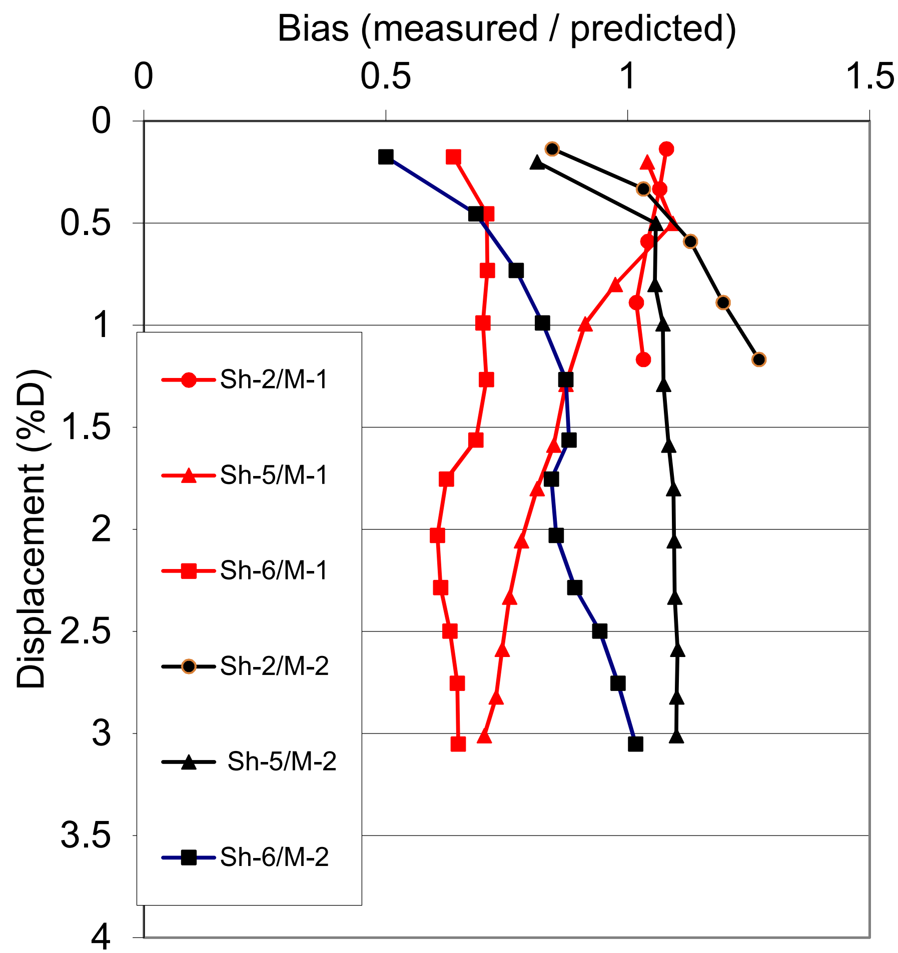
Types of Resistance Factors

- End Bearing Variables
  - End bearing is function of pressure
  - Pressure achieved on first or multiple stages
  - Field verification testing , and
  - Present, load test dependent
- Grout Pressure / Side Shear
  - Pressure is function of:
    - side shear, and
    - end bearing strata
  - Side shear in uplift, no reduction presently used

Compression	For soil: FHWA alpha or beta method [2]	0.6
	For rock socket: McVay's method [2] neglecting end bearing	0.6
	For rock socket: McVay's method [2] including 1/3 end bearing	0.55
	For rock socket: McVay's method [2]	0.7
	For rock socket: McVay's method [2]	0.75
Uplift	For clay: FHWA alpha method[3]	0.35
	For sand: FHWA beta method [3]	0.45
	For rock socket: McVay's method [2]	0.5

Design / Field / Reliability





Work Plan

- Task 1. Literature Review
- Task 2. Collect Post Grouting Case Study Data
- Task 3. Process Data / Analysis
- Task 4. Recommendations and Guidelines
- Task 5. Draft Report / Close-out Meeting
- Task 6. Final Report

Schedule

Description	Date
Project Kickoff Teleconference / Presentation webinar	February 2017
Task 1: Literature Review.	June 2017
Task 2. Collect Geotechnical Design Information.	November 2017
Task 3. Process Data and Analysis	April 2018
Task 4: Conclusions and Recommendations	October 2018
Task 5a: Draft Final Report	October 2018
Deliverable 5b – Closeout Meeting / Presentation	January 2019
Deliverable 6 – Final Report	January 2019


Questions