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# Design and Construction of High-Capacity Micropiles for ABC Projects

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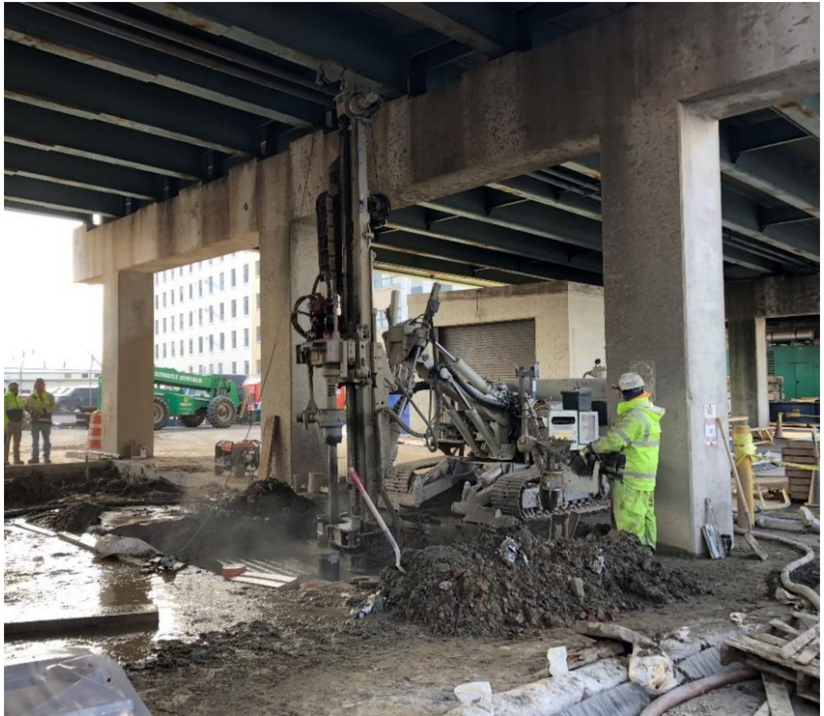
ABC-UTC Monthly Webinar
June 18, 2020

# Micropiles are a good choice for rapid bridge foundation installations. Although small in diameter, they can carry surprisingly high loadings with small deflections. They are not inexpensive, but they can be installed much quicker than drilled shafts and in limited-headroom and tight-access conditions.



# Presentation Outline

**Micropile Overview**

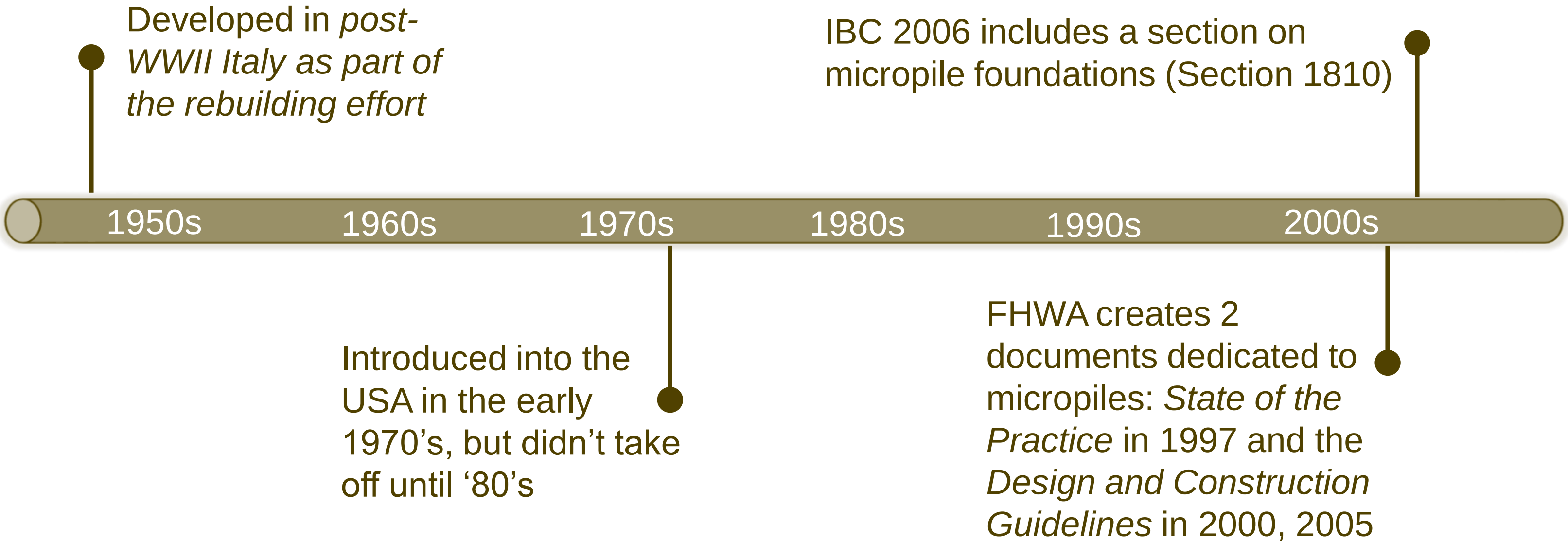
**Micropile Design**
  - Specifications
  - Design/Build

**Micropile Costs**

**Micropile Construction**
  - Materials
  - Equipment
  - Load Testing

**Case History**
  - Courtland Street Bridge, Atlanta

# Micropile Evolution Timeline



Developed in *post-WWII Italy as part of the rebuilding effort*

IBC 2006 includes a section on micropile foundations (Section 1810)

Introduced into the USA in the early 1970’s, but didn’t take off until ‘80’s

FHWA creates 2 documents dedicated to micropiles: *State of the Practice* in 1997 and the *Design and Construction Guidelines* in 2000, 2005

- With this history, micropiles are:
  - A non-proprietary geotechnical construction technique
  - Competitively bid by specialty contractors

# Micropiles in ABC-UTC Webinars

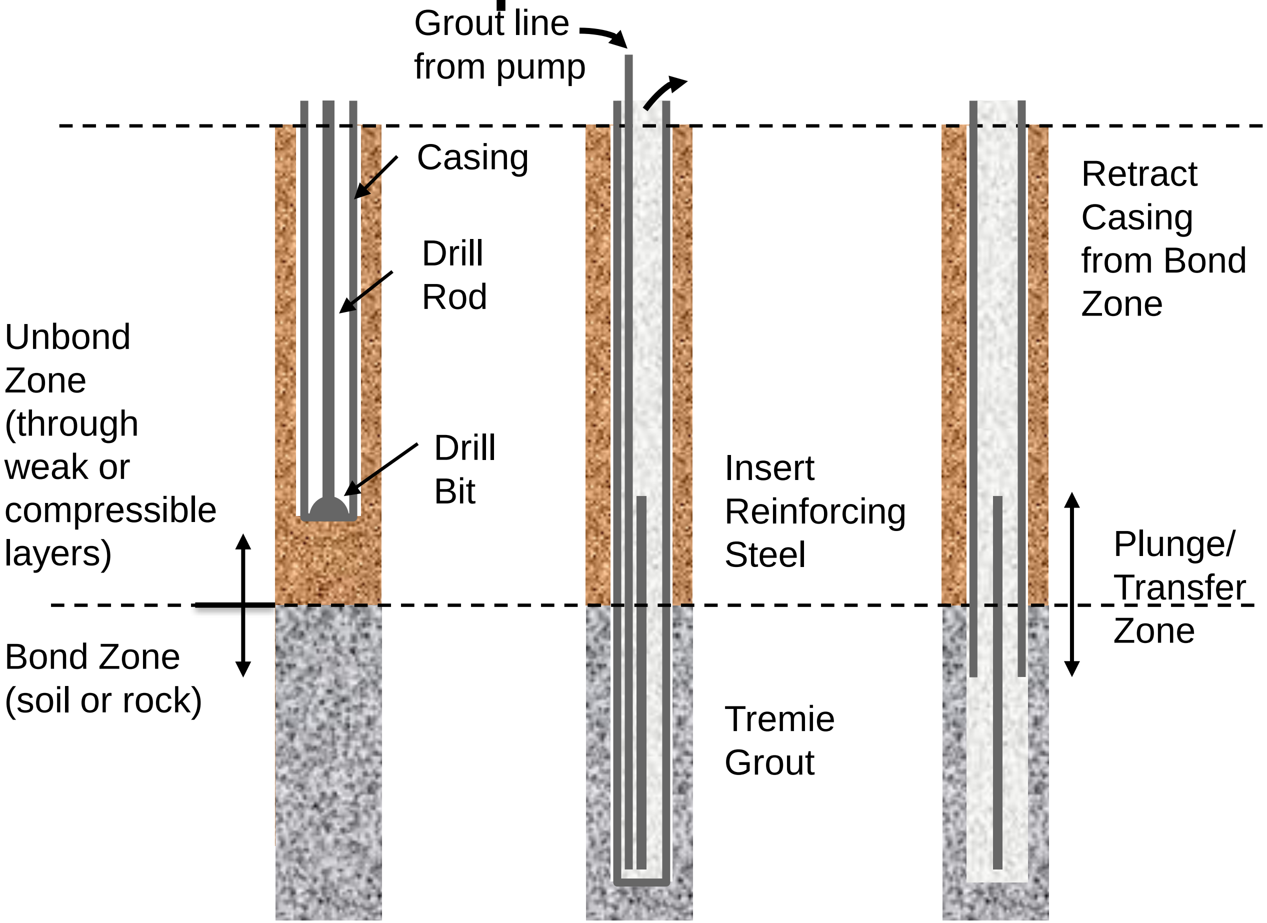
- February 13, 2020 – Tennessee DOT’s I-240 MemFix4 CMGC ABC Project
- December 19, 2019 – Connecticut DOT’s Atlantic Street Railroad Bridge Project
- Presentations available on ABC-UTC Monthly Webinar Archives

# “Micropiles Should Be Considered”:

- Where footings cannot be founded… at a reasonable expense
- Where soil conditions would normally allow spread footings but the potential for erosion exists
- At locations where pile foundations must penetrate rock
- Difficult subsurface conditions… would hinder driven piles or drilled shafts
- Difficult access or limited headroom preclude use of other deep foundation systems
- Foundations must bridge over or penetrate subsurface voids
- Vibration limits preclude pile driving or access by drilled shaft rigs
- When underpinning or retrofitting existing foundations

Ref. Section C10.9.1 AASHTO LRFD Bridge Design Specifications 8th Ed.

# Micropile Installation



Grout line from pump

Casing

Drill Rod

Drill Bit

Unbond Zone (through weak or compressible layers)

Bond Zone (soil or rock)

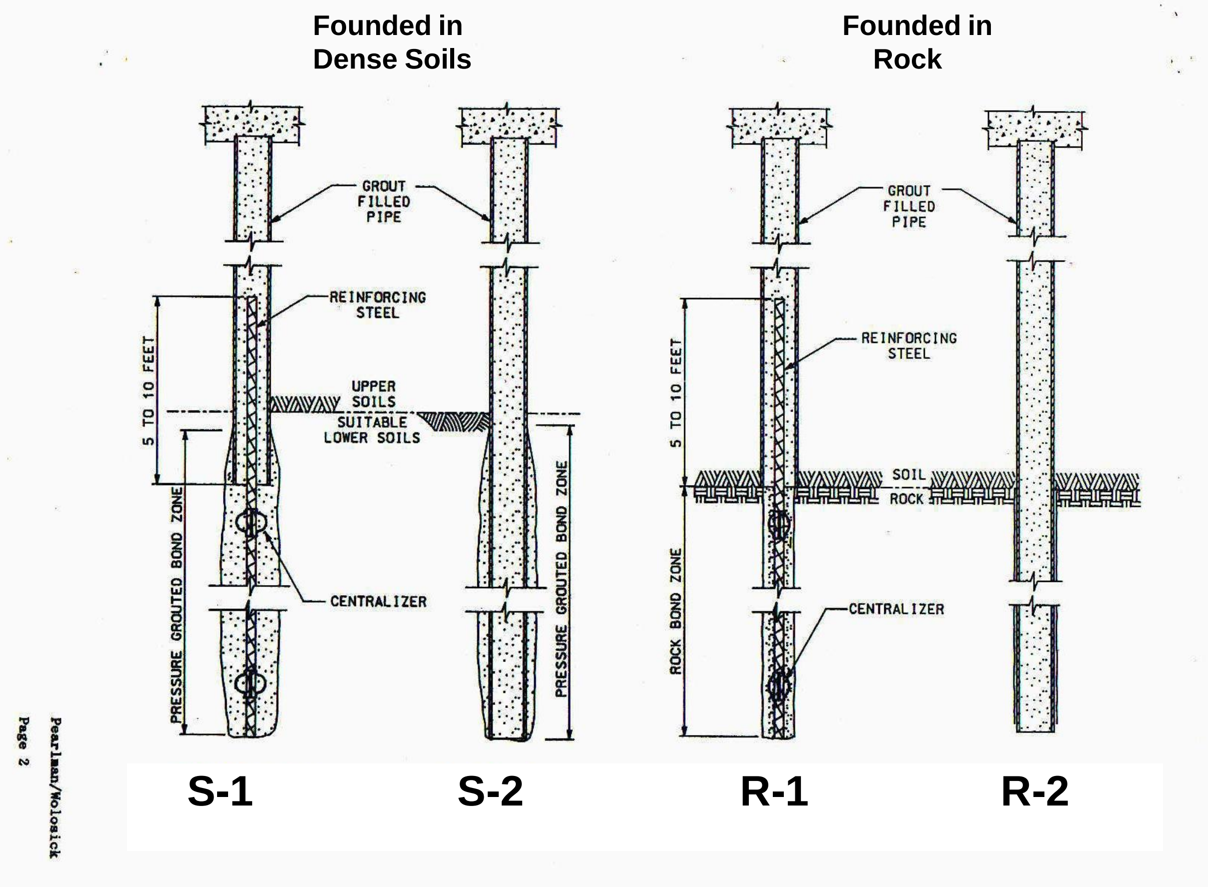
Insert Reinforcing Steel

Tremie Grout

Retract Casing from Bond Zone

Plunge/ Transfer Zone

# Micropile Types



**Founded in Dense Soils**

**Founded in Rock**

**S-1** **S-2** **R-1** **R-2**

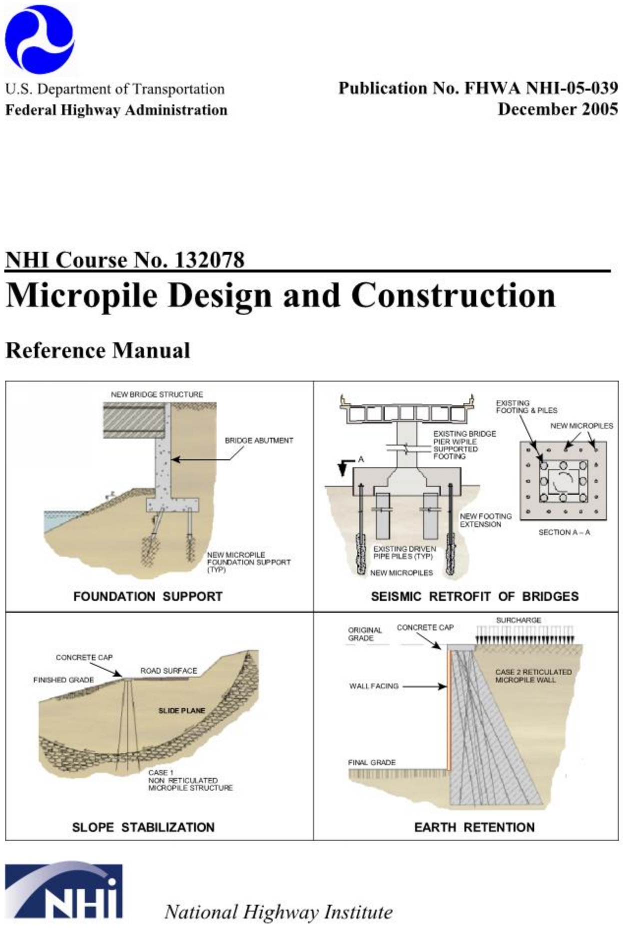
# Micropile Capacities

| Steel Pipe Sizes | Factored Resistance |
|---|---|
| • 5-½ inch diameter, 0.415-inch wall thickness: (6-½ inch drill hole) | 100 tons+ |
| • 7-inch diameter, 0.430 to 0.500-inch wall thickness<br>• 7-5/8-inch diameter, 0.500-inch wall thickness: (8 to 8-½ inch drill hole) | 125-150 tons+ |
| • 9-5/8-inch diameter, 0.472 to 0.545-inch wall thickness: (10-½ inch drill hole) | 175-200 tons+ |

# FHWA Micropile Manual 2005

## “The Best Reference for Micropile Design and Construction” ☺

Made available to attendees through ABC-UTC



U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA NHI-05-039
December 2005

NHI Course No. 132078

**Micropile Design and Construction**

**Reference Manual**

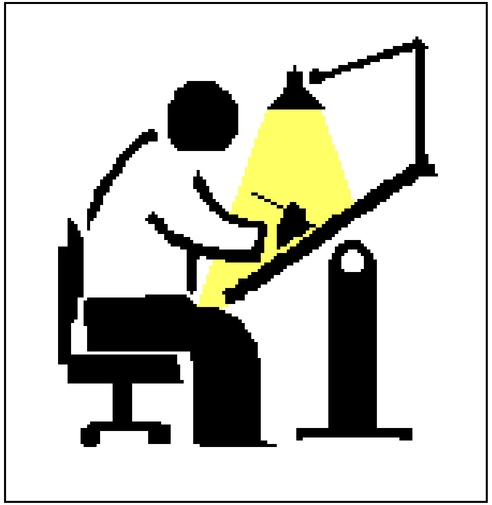
National Highway Institute

# Design/Build

- Micropiles are often a design/build component (or built using a performance specification) within individual projects.  Pre-qualification of experienced micropile contractors is typically required.
- Design/build micropiles are usually less expensive, since the contractor can tailor the constructed product to their equipment and experience.  Therefore, unfamiliar techniques and purchase of new equipment is not required to construct the project.
- Micropiles are occasionally design/bid/build, particularly in states where design/build is not allowed.

# Micropile Design Steps

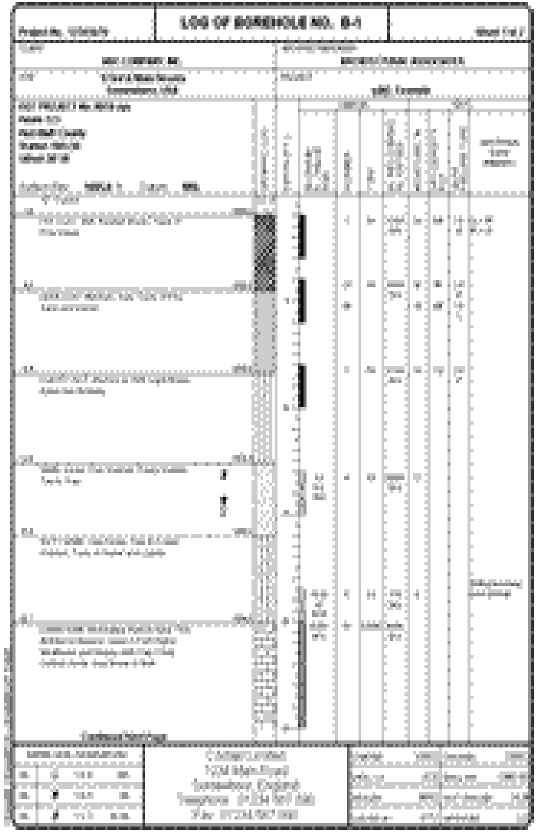
- External - Geotechnical
- Internal - Structural
- Connection of Pile to Structure



Note: Take advantage of high capacities provided and minimize the number of micropiles required to carry loads which will reduce costs

# Geotechnical Design:

- Good Quality Geotechnical Data
  - obtain soil samples/rock core and develop profiles
  - estimate design parameters
  - evaluate corrosion potential
  - identify problem areas, if any



LOG OF BOREHOLE NO. B-1

# Geotechnical Capacity

- Factored Resistance = $R_R = \underbrace{\cancelto{= 0}{\emptyset_{qp} * R_p}}_{\text{Tip Resistance}} + \underbrace{\emptyset_{qs} * R_s}_{\text{Side Resistance}}$

Eq. 10.9.3.5.1-1
AASHTO 8th Ed.

where:

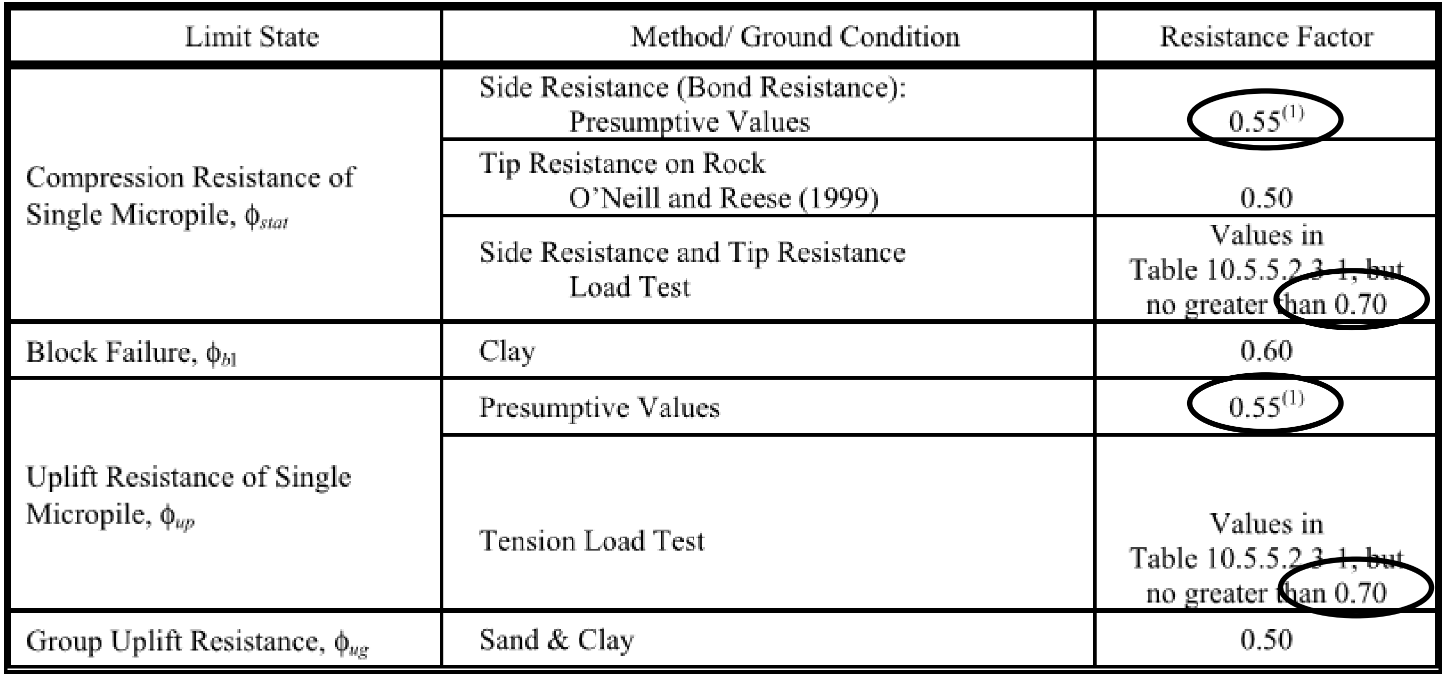
$\phi_{qs}$ = resistance factor from table 10.5.5.2.5-1 AASHTO 8th Ed.

$R_s = q_s * A_s$

$q_s$ = grout-to-ground bond resistance (ultimate resistance)

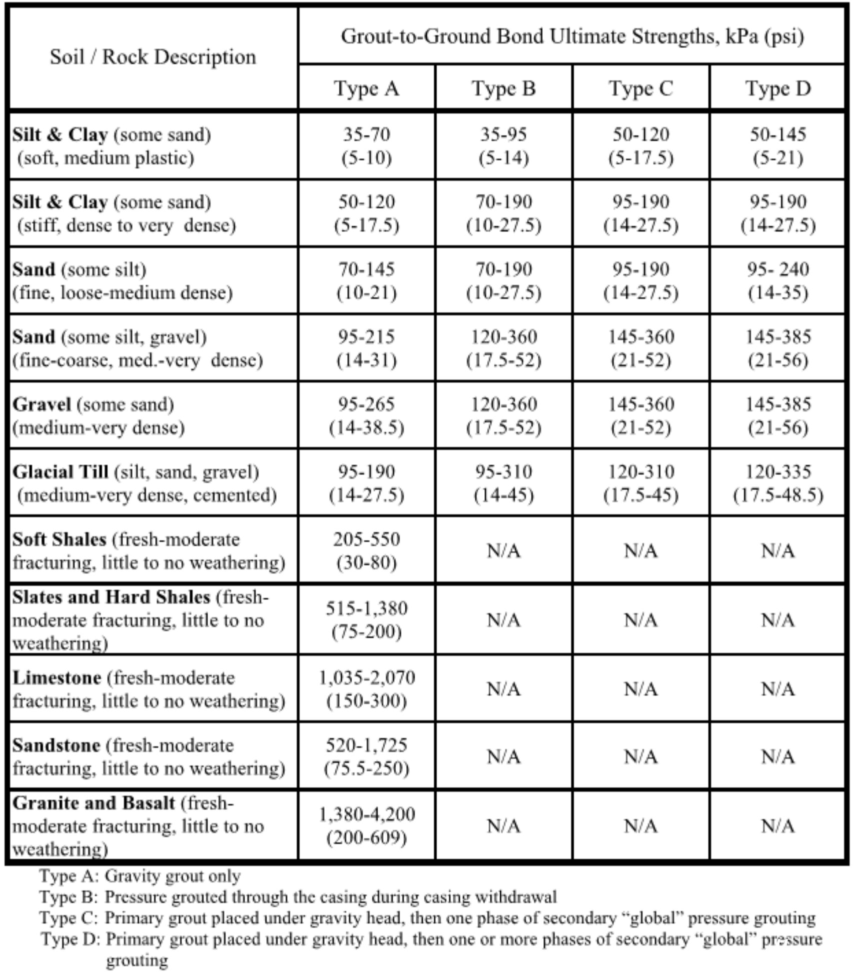
$A_s$ = bond zone area = pi * bond zone diameter *bond zone length

# Geotechnical Resistance Factors



| Limit State | Method/ Ground Condition | Resistance Factor |
|---|---|---|
| Compression Resistance of Single Micropile, $\phi_{stat}$ | Side Resistance (Bond Resistance):<br>Presumptive Values | 0.55(1) |
| | Tip Resistance on Rock<br>O'Neill and Reese (1999) | 0.50 |
| | Side Resistance and Tip Resistance<br>Load Test | Values in Table 10.5.5.2.3-1, but no greater than 0.70 |
| Block Failure, $\phi_{bl}$ | Clay | 0.60 |
| Uplift Resistance of Single Micropile, $\phi_{up}$ | Presumptive Values | 0.55(1) |
| | Tension Load Test | Values in Table 10.5.5.2.3-1, but no greater than 0.70 |
| Group Uplift Resistance, $\phi_{ug}$ | Sand & Clay | 0.50 |

Ref. Table 10.5.5.2.5-1 AASHTO 8th Ed.



| Soil / Rock Description | Grout-to-Ground Bond Ultimate Strengths, kPa (psi) | | | |
|---|---|---|---|---|
| | Type A | Type B | Type C | Type D |
| **Silt & Clay** (some sand) (soft, medium plastic) | 35-70<br>(5-10) | 35-95<br>(5-14) | 50-120<br>(5-17.5) | 50-145<br>(5-21) |
| **Silt & Clay** (some sand) (stiff, dense to very dense) | 50-120<br>(5-17.5) | 70-190<br>(10-27.5) | 95-190<br>(14-27.5) | 95-190<br>(14-27.5) |
| **Sand** (some silt) (fine, loose-medium dense) | 70-145<br>(10-21) | 70-190<br>(10-27.5) | 95-190<br>(14-27.5) | 95- 240<br>(14-35) |
| **Sand** (some silt, gravel) (fine-coarse, med.-very dense) | 95-215<br>(14-31) | 120-360<br>(17.5-52) | 145-360<br>(21-52) | 145-385<br>(21-56) |
| **Gravel** (some sand) (medium-very dense) | 95-265<br>(14-38.5) | 120-360<br>(17.5-52) | 145-360<br>(21-52) | 145-385<br>(21-56) |
| **Glacial Till** (silt, sand, gravel) (medium-very dense, cemented) | 95-190<br>(14-27.5) | 95-310<br>(14-45) | 120-310<br>(17.5-45) | 120-335<br>(17.5-48.5) |
| **Soft Shales** (fresh-moderate fracturing, little to no weathering) | 205-550<br>(30-80) | N/A | N/A | N/A |
| **Slates and Hard Shales** (fresh-moderate fracturing, little to no weathering) | 515-1,380<br>(75-200) | N/A | N/A | N/A |
| **Limestone** (fresh-moderate fracturing, little to no weathering) | 1,035-2,070<br>(150-300) | N/A | N/A | N/A |
| **Sandstone** (fresh-moderate fracturing, little to no weathering) | 520-1,725<br>(75.5-250) | N/A | N/A | N/A |
| **Granite and Basalt** (fresh-moderate fracturing, little to no weathering) | 1,380-4,200<br>(200-609) | N/A | N/A | N/A |

Type A: Gravity grout only
Type B: Pressure grouted through the casing during casing withdrawal
Type C: Primary grout placed under gravity head, then one phase of secondary "global" pressure grouting
Type D: Primary grout placed under gravity head, then one or more phases of secondary "global" pressure grouting

- Ranges of Ultimate Bond Stresses in Soils and Rocks
- Table 5-3 FHWA Micropile Manual
- Also Table C10.9.3.5.2-1 AASHTO 8th Ed.

# Structural Capacity - Compression

- The factored resistance in compression of the piles is as follows:
- $R_{cc} = \text{Ø}_c * 0.85 * (0.85 * f`_c * A_g + F_y * A_s)$

Eqs. 10.9.3.10-2a-2 and 2b-2 AASHTO 8th Ed.

- Where,

$\phi_c$ = resistance factor from table 10.5.5.2.5-2 AASHTO 8th Ed.

$f`_c$ = UCS of grout

$A_g$ = Net area of grout

$F_y$ = Yield strength of steel

$A_s$ = Area of Steel (casing and/or bar)

Note: $F_y$ limited to stress at 0.003 strain (Section C10.9.3.10.2a AASHTO 8th Ed.)

# Structural Capacity - Tension

- The factored resistance in tension of the piles can be calculated as follows:
- $R_{tc} = \emptyset_t * F_y * A_s$ Eqs. 10.9.3.10-3a-2 and 3b-2 AASHTO 8th Ed.
- Where,

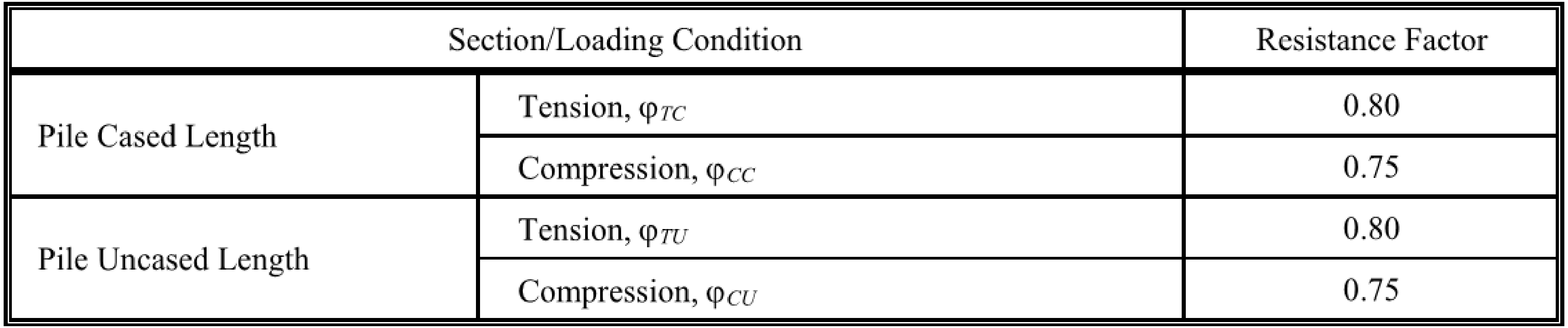
$\phi_t$ = resistance factor from AASHTO Table 10.5.5.2.5-2 (AASHTO 8th Ed.)

$F_y$ = Yield strength of the steel

$A_s$ = Area of Steel (casing and/or bar)

Note: $F_y$ limited to stress at 0.003 strain (Section C10.9.3.10.2a AASHTO $8^{th}$ Ed.)

# Structural Resistance Factors



| Section/Loading Condition | | Resistance Factor |
|---|---|---|
| Pile Cased Length | Tension, $\varphi_{TC}$ | 0.80 |
| | Compression, $\varphi_{CC}$ | 0.75 |
| Pile Uncased Length | Tension, $\varphi_{TU}$ | 0.80 |
| | Compression, $\varphi_{CU}$ | 0.75 |

Ref. Table 10.5.5.2.5-2 AASHTO LRFD Bridge Design Specifications 8th Ed.

# Additional Design Notes

- Consider loading combinations, especially at pipe joints.  If a problem, consider no joints in upper 10 feet or use upper double casing.
- Lateral load capacity is limited due to small diameters and is a soil/structure interaction assessment.  Loose or soft soils reduce lateral capacity.  Use software such as Lpile to evaluate (typically conservative).
- Evaluate corrosion potential.  Use sacrificial steel (1/8-inch) and/or epoxy coating on the thread-bars.

# Typical Micropile Prices - 2020 (mill secondary casing)

- **Non-Union Areas:**

  **Open Headroom: $75-$90/LF**

  **Low Headroom: $100/LF+**

- **Union Areas: Add 15-20%**

# Materials - Casing

- Oil Well Casing – API standards
- $F_y$= 80 ksi (Note! High Strength Steel)
- Threaded Pipe Sections
- ~0.5-inch wall thickness
- “Structural Grade” mill secondary – no mill certificates
- Casing made in USA but does not comply with Buy America(n) – “Prime” casing which comes with mill certificates is very expensive.

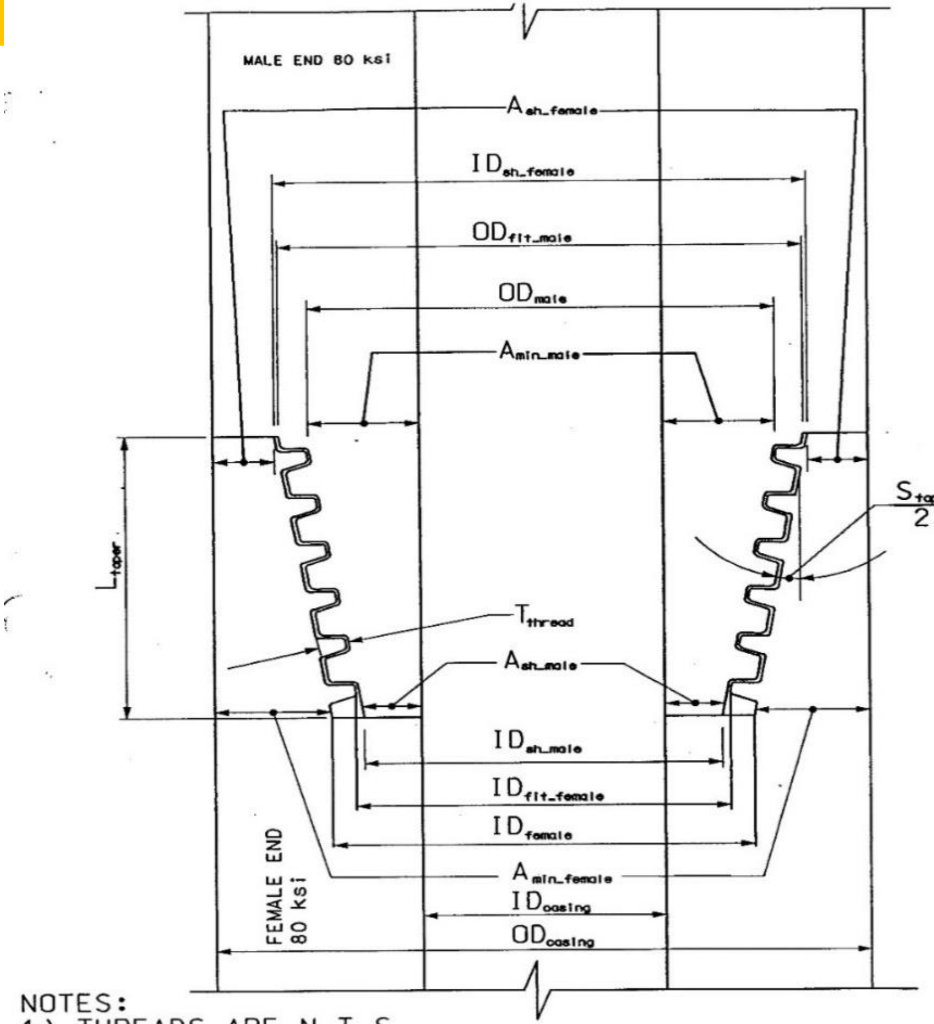
5.5, 7, 9.625-inch OD most common sizes

# Pipe/Casing Tapered and Threaded Joints

Provides 100% Load in Compression

Provides 50% in Bending

Provides about 50% in Tension, or carried by thread-bars

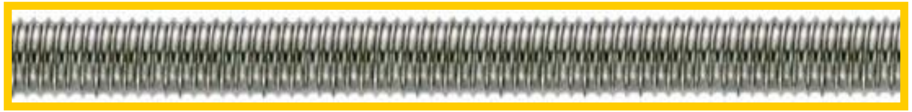


NOTES:
1) THREADS ARE N.T.S.
2) TAPER AND WALL ARE EXAGGERATED

# Materials - Steel thread-bars

**Dywidag**

**Williams**



- Steel Grades
  - Grade 60
  - Grade 75
  - Grade 80, 95, 100
  - Grade 150 ($f_y$ = 120 ksi)
- Coupled bars

# Steel Bar with Plastic Centralizer

# Materials - Grout

- Neat Cement with water/cement ratio of 0.45 (no aggregate)
- Admixtures may be SuperPlasticizer (water reducer)
- Compressive strength of 4,000-6,000 psi for design calculations
- Batched on-site

# Grout Installation

## Tremie Grout

## Pressure Grout

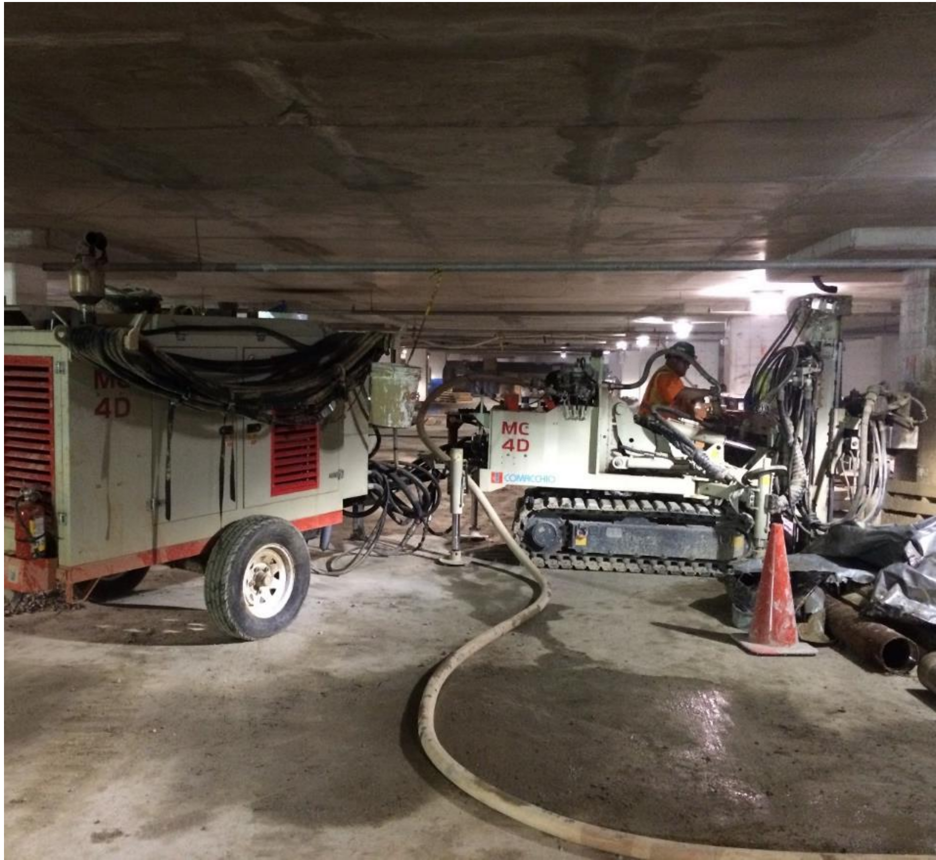
# Tension Connections

# Equipment

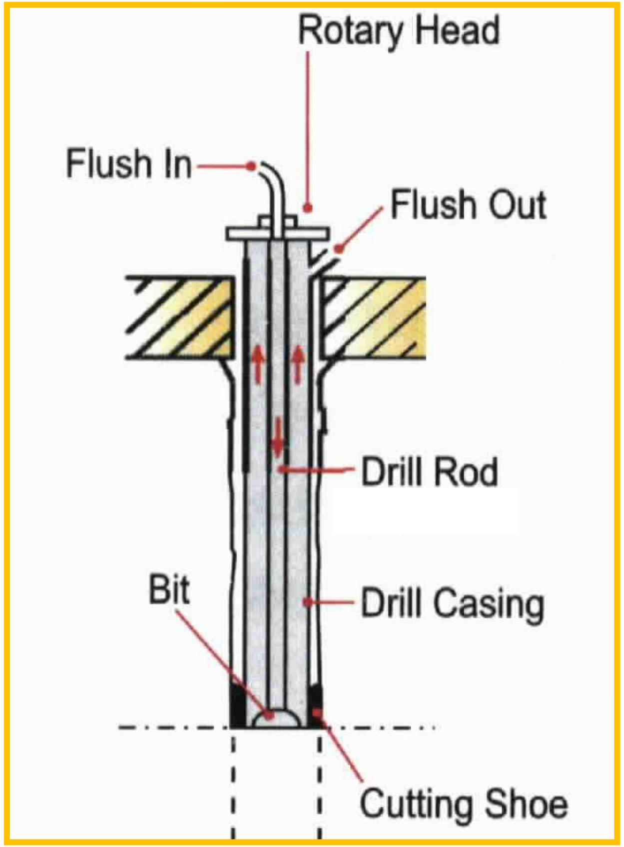
- **Drilling: Modern Hydraulic Drills**

- From oil well industry
- Very fast drilling speeds: 1-2 ft/minute
- Same rate in soil or rock!

**Project:**
**Low-overhead restriction**
**60-foot piles installed in 3-foot sections**



# Duplex Drilling

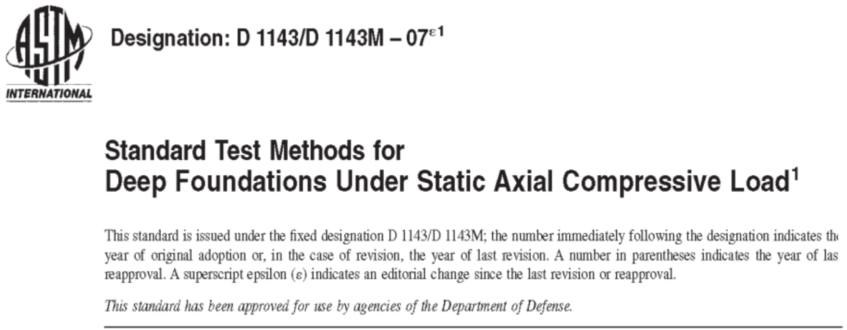


- Often specified - less risk than open hole drilling
- Minimal loss of ground in cohesionless soils
- Grouted through the casing - then pulled with tremie head or excess pressure

# Duplex Drill Casing and Down-the-Hole Hammer

# Load Testing

- Micropiles react similarly in compression and in tension (note same resistance factor). Therefore, tension testing, which costs ¼ compared to compression testing, is used frequently, and provides conservative results since no end-bearing occurs.

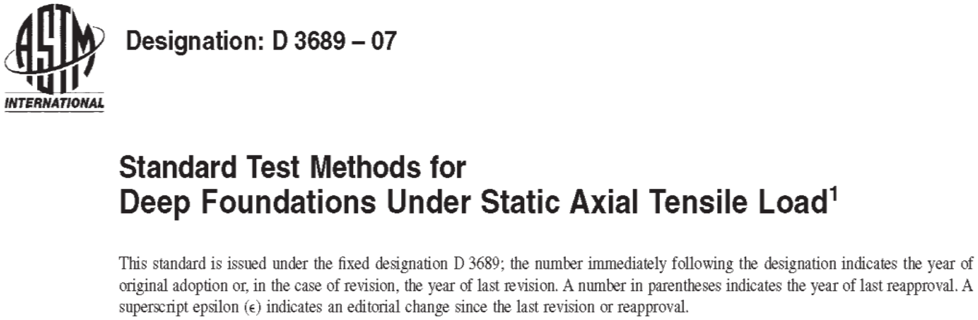


**Designation: D 1143/D 1143M – 07$^{\varepsilon 1}$**

**Standard Test Methods for**
**Deep Foundations Under Static Axial Compressive Load[1]**

This standard is issued under the fixed designation D 1143/D 1143M; the number immediately following the designation indicates th year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of las reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

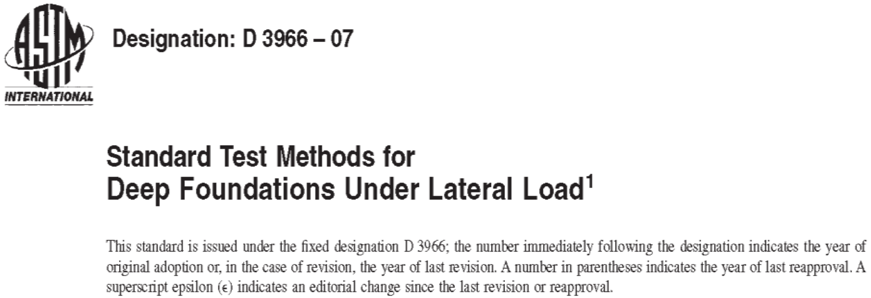
*This standard has been approved for use by agencies of the Department of Defense.*



**Designation: D 3689 – 07**

**Standard Test Methods for**
**Deep Foundations Under Static Axial Tensile Load[1]**

This standard is issued under the fixed designation D 3689; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.



**Designation: D 3966 – 07**

**Standard Test Methods for**
**Deep Foundations Under Lateral Load[1]**

This standard is issued under the fixed designation D 3966; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

# Compression Test requires 4 tiedown anchors which are expensive

# Lateral Load Test – 2 for 1!
# Concentric steel pipe for additional lateral resistance
# Tappan Zee Bridge Replacement (2018)

12-inch diameter

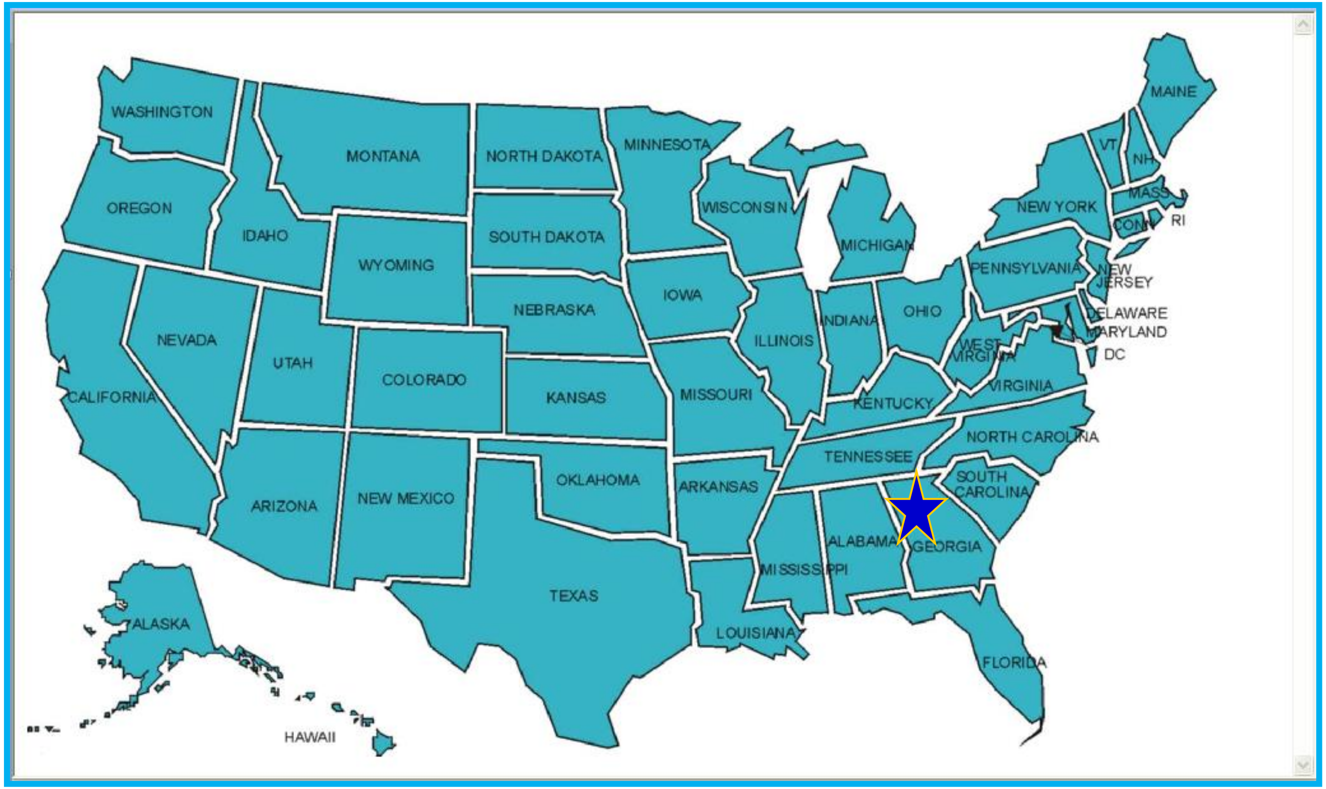
# ABC - Courtland Street Bridge Replacement Atlanta, Georgia 2018

- $21 million bridge replacement – design/build ($25 million estimate)
- Approximately 80% of the new bridge micropiles/substructure were installed prior to demolition of the old bridge
- 2019 Small Project Award by Design-Build Institute of America

# Project Details

- Georgia DOT design/build letting – July 2017
    - Contractor – C.W. Matthews Contracting Company
    - Designer – Michael Baker International
    - Micropile design/build subcontractor – Keller North America
- Schedule driven
    - Project of this size normally a 2-year duration
    - Project requirement - existing bridge out of service for 155 days

# Project Location – Atlanta, Georgia



# Project Details

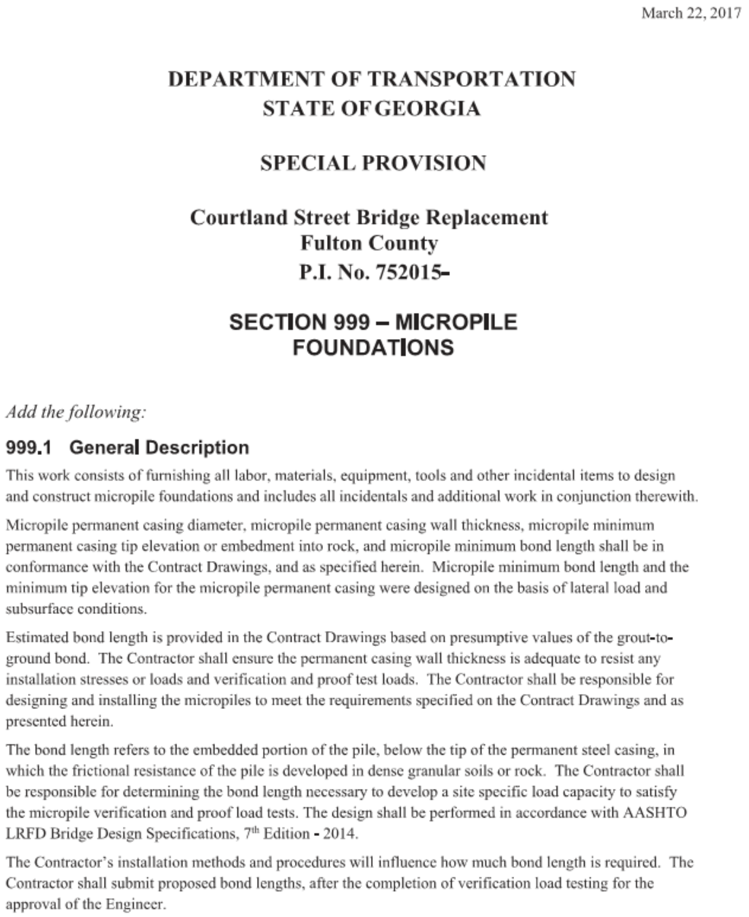
- 1,131 ft, 28-span viaduct replacement
- ADT - 18,400
- 12-span bridge with 4-lanes and sidewalks
- 3 micropile verification tests
- 13 micropile proof tests – 1 per bent
- Conventional superstructure construction (no sliding bridge or off-site construction)
- See time lapse at www.dot.ga.gov/buildsmart/projects/pages/courtlandst.aspx

Georgia State University
30,000 students

State Capital Building

CSX RR
MARTA (rapid transit)

KELLER



March 22, 2017

DEPARTMENT OF TRANSPORTATION
STATE OF GEORGIA

SPECIAL PROVISION

Courtland Street Bridge Replacement
Fulton County
P.I. No. 752015-

## SECTION 999 – MICROPILE FOUNDATIONS

*Add the following:*

### 999.1 General Description

This work consists of furnishing all labor, materials, equipment, tools and other incidental items to design and construct micropile foundations and includes all incidentals and additional work in conjunction therewith.

Micropile permanent casing diameter, micropile permanent casing wall thickness, micropile minimum permanent casing tip elevation or embedment into rock, and micropile minimum bond length shall be in conformance with the Contract Drawings, and as specified herein. Micropile minimum bond length and the minimum tip elevation for the micropile permanent casing were designed on the basis of lateral load and subsurface conditions.

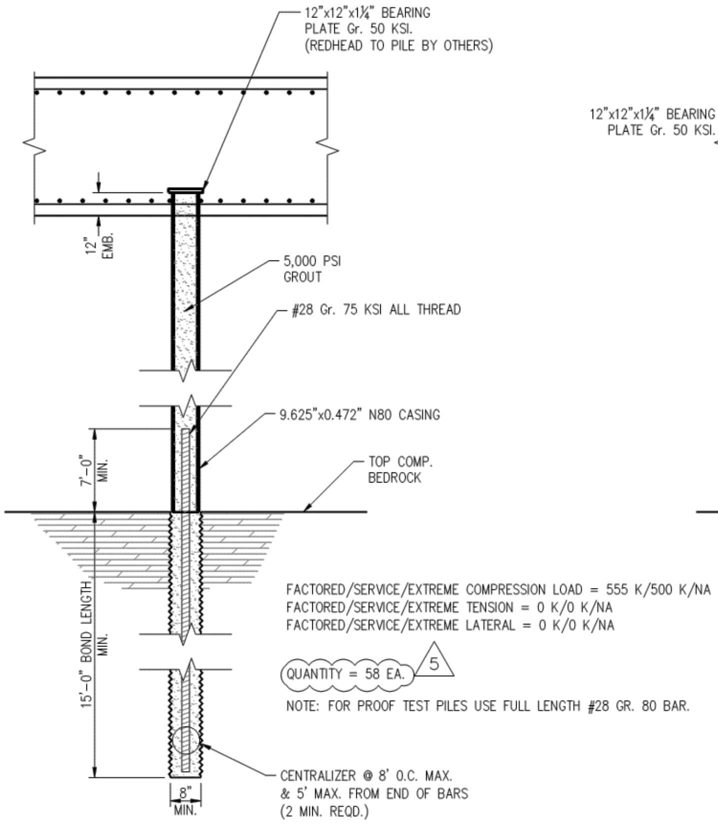
Estimated bond length is provided in the Contract Drawings based on presumptive values of the grout-to-ground bond. The Contractor shall ensure the permanent casing wall thickness is adequate to resist any installation stresses or loads and verification and proof test loads. The Contractor shall be responsible for designing and installing the micropiles to meet the requirements specified on the Contract Drawings and as presented herein.

The bond length refers to the embedded portion of the pile, below the tip of the permanent steel casing, in which the frictional resistance of the pile is developed in dense granular soils or rock. The Contractor shall be responsible for determining the bond length necessary to develop a site specific load capacity to satisfy the micropile verification and proof load tests. The design shall be performed in accordance with AASHTO LRFD Bridge Design Specifications, 7th Edition - 2014.

The Contractor's installation methods and procedures will influence how much bond length is required. The Contractor shall submit proposed bond lengths, after the completion of verification load testing for the approval of the Engineer.

# Many states, such as Georgia Section 999 shown here, have written their own micropile special provisions or specifications

# Courtland Street Bridge Micropile Sections

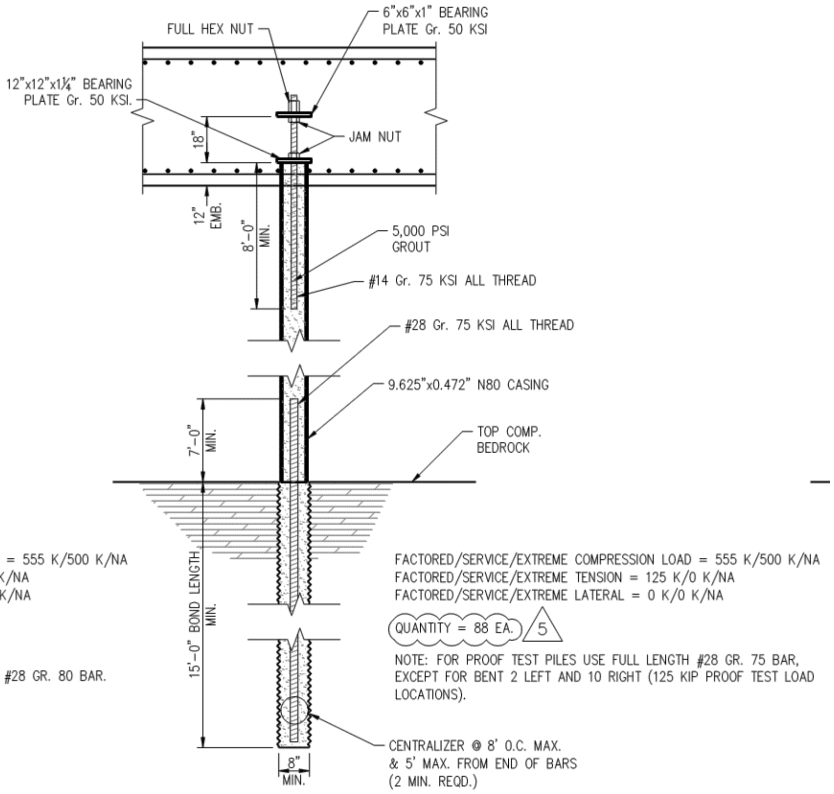


FACTORED/SERVICE/EXTREME COMPRESSION LOAD = 555 K/500 K/NA
FACTORED/SERVICE/EXTREME TENSION = 0 K/0 K/NA
FACTORED/SERVICE/EXTREME LATERAL = 0 K/0 K/NA

QUANTITY = 58 EA.

NOTE: FOR PROOF TEST PILES USE FULL LENGTH #28 GR. 80 BAR.

MICROPILE DETAIL
NO SCALE



FACTORED/SERVICE/EXTREME COMPRESSION LOAD = 555 K/500 K/NA
FACTORED/SERVICE/EXTREME TENSION = 125 K/0 K/NA
FACTORED/SERVICE/EXTREME LATERAL = 0 K/0 K/NA

QUANTITY = 88 EA.

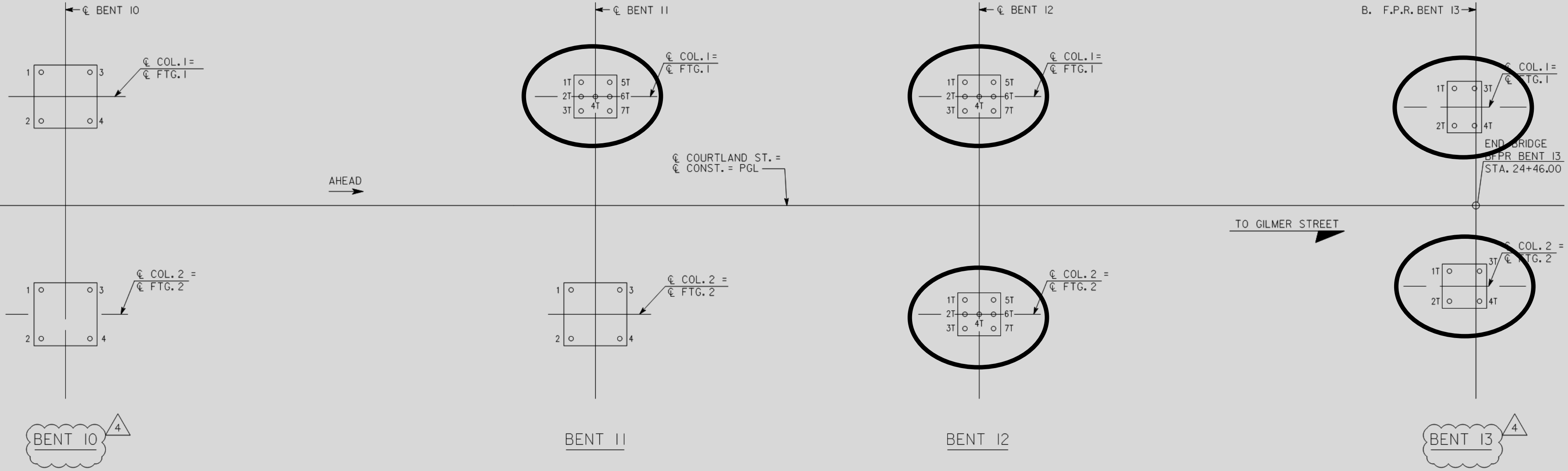
NOTE: FOR PROOF TEST PILES USE FULL LENGTH #28 GR. 75 BAR, EXCEPT FOR BENT 2 LEFT AND 10 RIGHT (125 KIP PROOF TEST LOAD LOCATIONS).

MICROPILE DETAIL W/ TENSION
NO SCALE

KELLER

# Bridge Foundation Plan – Bents 10 to 13

## Compression-Tension Micropiles



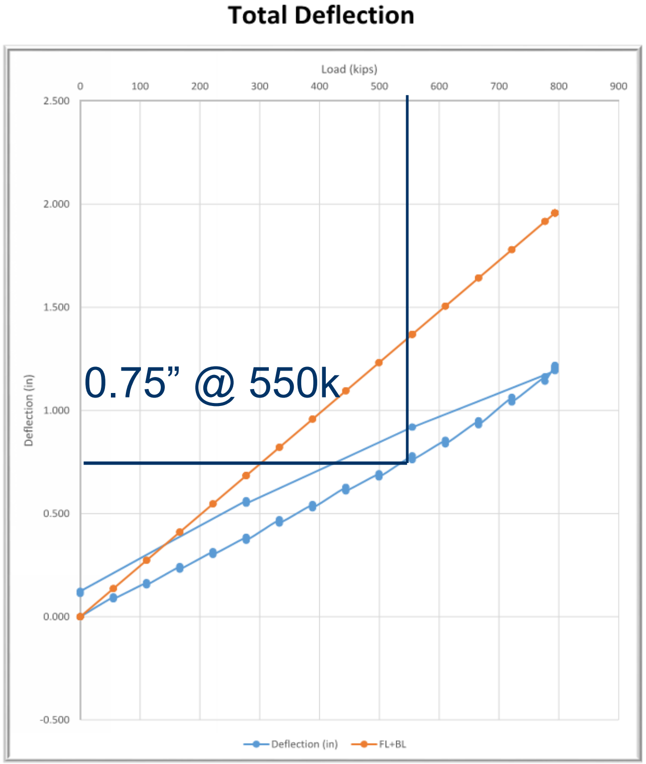
Micropile installation under existing in-service bridge

5-foot long drilling tool sections added with separate machine

# Tremie Grouting Neat Cement. Tremie extends to the bottom of the pile.

# Tension Load Test – Courtland Street Bridge

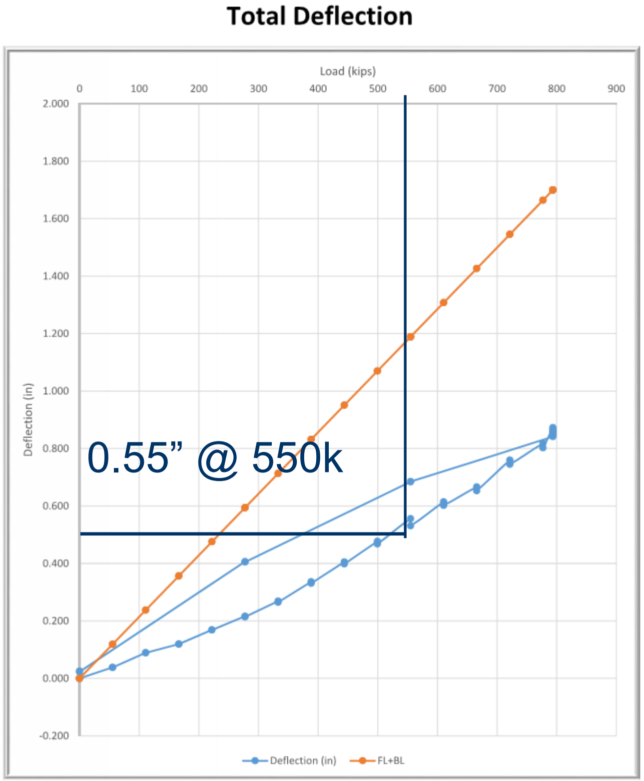
## 90-foot micropile



0.75” @ 550k

- 800 k (400 ton) test load
- 9-5/8-inch OD GR80 steel pipe
- Tension Tests

## 68-foot micropile



0.55” @ 550k

# Project Summary

- Construction began November 2017
- Actual bridge out of service dates – May 6 to October 4 (ribbon cutting)

- Micropile Lessons Learned
  - Old fill, 100-year-old utilities – expect the worst
  - Tension testing
    - Economical ~ $400,000 reduction in testing cost

# Summary – Micropile Bridge Applications

- Widening
- Abutments
- Retrofits/underpinning
- Erratic or difficult subsurface profile
- Piles socketed into bedrock
- GREAT FOR ABC CONSTRUCTION!

# End

- **Thank you for your attention.**
- **Submitted questions will be answered as time allows.**

**Paul Liles**

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