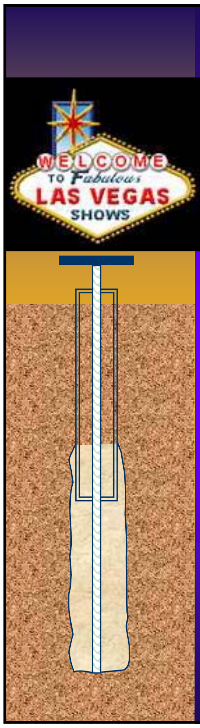
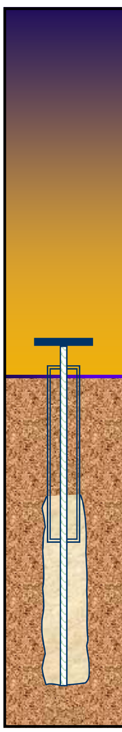


Micropiles Design 101

Allen Cadden, P.E.
West Chester, PA

Schnabel Engineering

Las Vegas, NV 2008



Objective

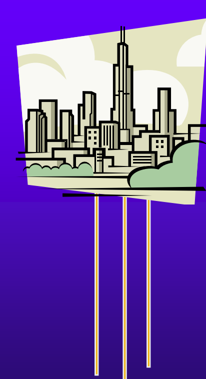
- Develop a background understanding of the geotechnical and structural design processes for micropiles in structural foundation support applications

Contents

1. Background for Engineers
2. Structural Design
3. Geotechnical Design
4. Additional Considerations
5. Brief Design Example

1. Background for Engineers

- Fundamentals are similar to traditional pile design
- However, due to the small structural section, structural design and stiffness can often control



Designers Must Understand Available Tools

- Drilling rigs
- Drilling methods
- Available Structural Materials
- Reasonable Bond Values
- Quality Control

Construction Techniques

"Drill Rig"

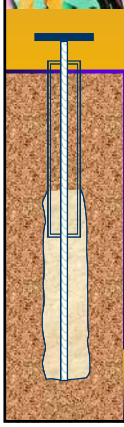
Micropile Materials

- **Permanent Steel Pipe**
  - API 5CT & ASTM A252
  - 80 ksi yield
  - Flush joint threads
- **Steel Reinforcement**
  - ASTM A615, Gr. 60 & 75
  - ASTM A722, Gr. 150
  - Mechanical coupling
  - Hollow bars
- **Cement Grout**
  - Neat cement – ASTM C150
  - W/C ratio of 0.45
  - 4000 psi (min)

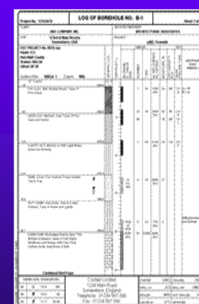
Design Involves:

- Knowing the site
- Understanding the loads
- Understanding the geology
- Calculations
- Specifications
- Quality Control

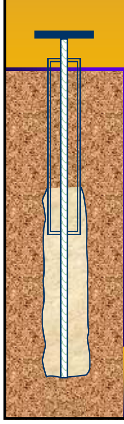
A Word on Geology



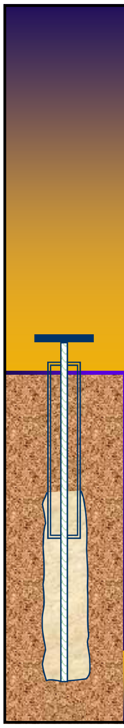
- Review of Geotechnical Data
  - obtain samples and **develop sections**
  - estimate design parameters
  - evaluate corrosion potential
  - identify problem areas, if any



Micropile Design Steps



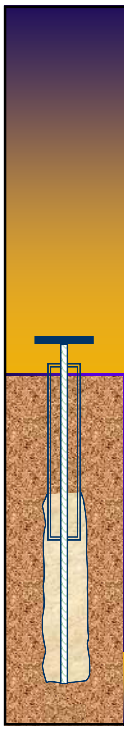
- Internal - Structural
- External - Geotechnical
- Connection of Pile to Structure



2. Structural Design

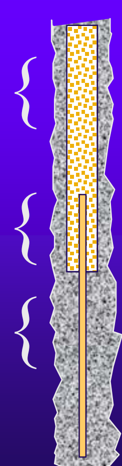
- Components
  - Cased length
  - Uncased length
  - Grout to steel bond
  - Transitions between reinforcement types
  - Strain compatibility
  - Casing or bar splice and connection
  - Footing connection

{ Compression
Tension
Bending
Combinations



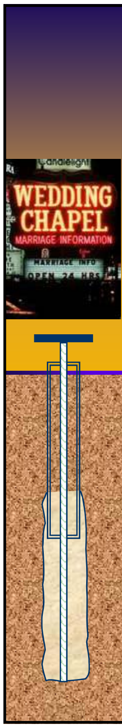
Structural Design (internal)

- Grout & steel
- Transfer zone
- Bond zone



IBC 2006 code allowable stresses

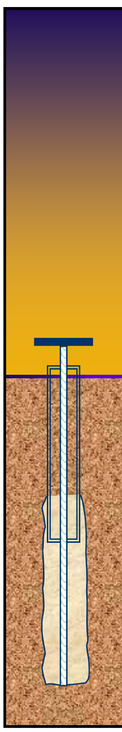
- Compression
  - Grout: 0.33 f'c
  - Steel: 0.4 fy
    - max 32ksi
- Tension
  - Grout: 0
  - Steel: 0.6 fy



Allowable Stresses

CODE	Compression					Tension	
				ALLOWABLE STEEL STRESS (MPa)	ALLOWABLE GROUT STRESS (MPa)		
	CASING	BAR	GROUT	fy=550 Mpa	f'c=34.5 Mpa	CASING	BAR
ACI with LF = 1.55	0.45	0.45	0.38	249.1	13.2	0.58	0.58
FHWA Micropiles	0.47	0.47	0.40	259.2	13.8	0.55	0.55
AASHTO Caisson	0.35	0.35	0.30	193.1	10.3	0.35	0.35
AASHTO Driven Unfilled with increase for unlikely damage	0.33	0.33	0.40	113.8	13.8	0.33	0.33
AASHTO Driven Concrete Filled NO increase for unlikely damage	0.25	0.25	0.40	86.2	13.8	0.33	0.33
JAMP	0.59	0.59		324.5		0.59	0.59

2006 IBC: 0.33f'c, 0.4fy (max 32ksi) compression: 0.6fy tension



AASHTO LRFD Design

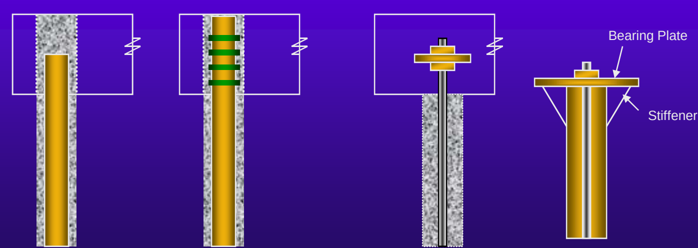
Table 10.5.5.2.4-2 - Resistance Factors for Structural Resistance of Axially Loaded Micropiles

METHOD/SOIL/CONDITION		RESISTANCE FACTOR
Pile Cased Length	Tension, φ_{TC}	0.80
	Compression, φ_{CC}	0.75
Pile Uncased Length	Tension, φ_{TU}	0.80
	Compression, φ_{CU}	0.75

DRAFT

Connection Details

- Shear transfer from grout
- Bearing plate
- Shear rings



Connection Strength Research

ISM 2006

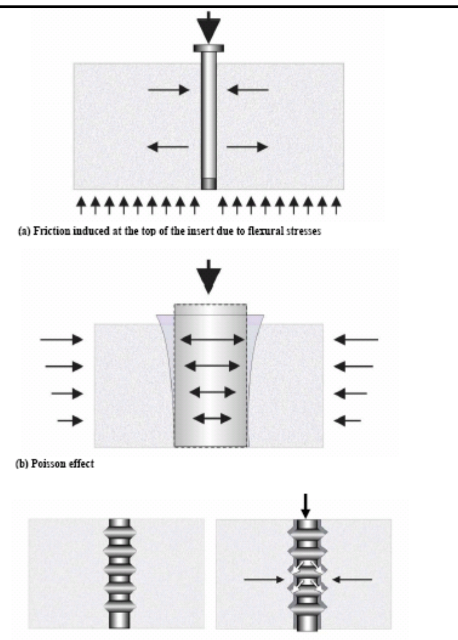


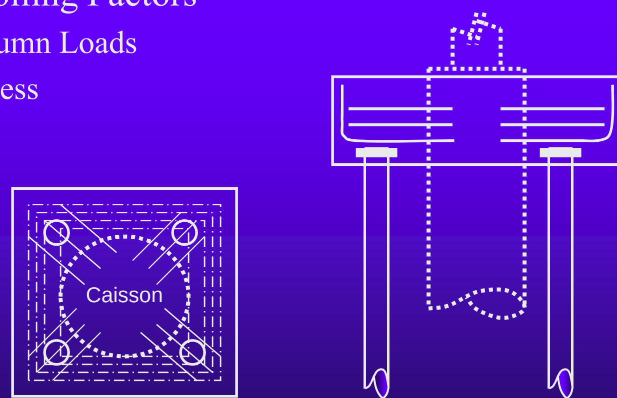
Figure 34. Illustration of Three Mechanisms Inducing Friction at the Interface Between the Micropile Insert and the Surrounding Grout or Concrete

35

Gómez & Cadden
Schnabel Engineering

Caisson Repair - Connections

- Controlling Factors
  - Column Loads
  - Access

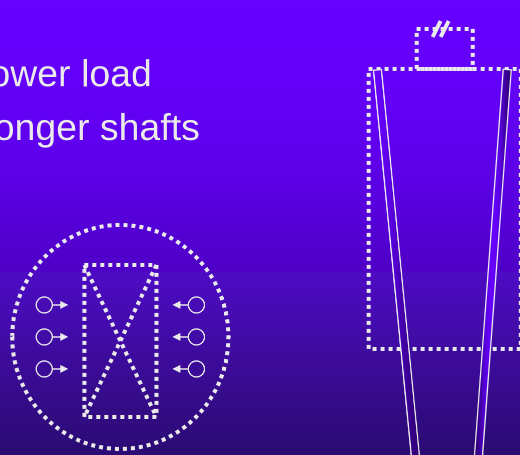


Short Shaft, Very High Load

Caisson Repair

Lower load

Longer shafts



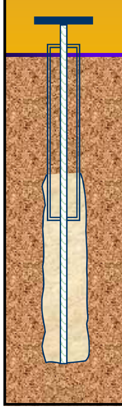
Connection Examples

Do we need plates?

3. Geotechnical Design

- Evaluate Load Transfer Parameters
  - grout to ground average bond values
  - identify variations throughout profile and across the site
  - define the required minimum bond length
- Evaluate pile spacing
  - impact from group effects

Geotechnical Design - Rational (external)

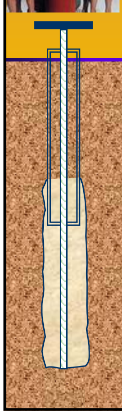


- FHWA
  - β method - cohesionless
  - α method - cohesive
  - grout pressure increases bond
- Rock
  - Bruce, FHWA, PTI
  - Based on q_u
  - local bldg. code limits

PTI

bond values for gravity and pressure grouted (>50psi) anchors

Geotechnical Capacity (ASD)



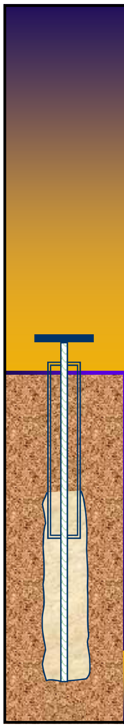
$$P_{G-allowable} = \frac{\alpha_{bond}}{FS} \times \pi \times D_b \times L_b$$

α_{bond} = grout to ground ultimate bond strength

FS = factor of safety applied to the ultimate bond strength

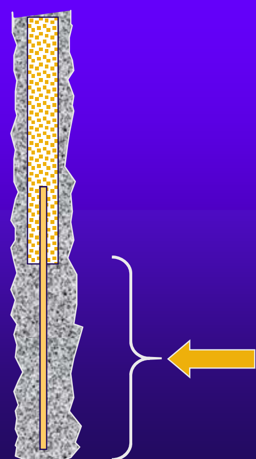
D_b = diameter of the drill hole

L_b = bond length

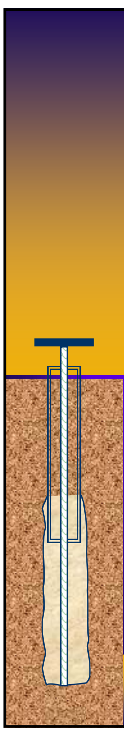


Calculate Bond Length

Rearranging this a bit



$$L_b = \frac{P_{G-allowable} \times FS}{\alpha_{bond} \times \pi \times D_b}$$

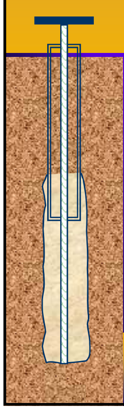


AASHTO LRFD Design

Table 10.5.5.2.4-1 - Resistance Factors for Geotechnical Resistance of Axially Loaded Micropiles

METHOD/SOIL/CONDITION		RESISTANCE FACTOR
Compression Resistance of Single Micropile, ϕ_{stat}	Side Resistance (Bond Resistance): Presumptive Values	0.55[(1)]
	Tip Resistance on Rock O'Neill and Reese (1999)	0.50
	Side Resistance and Tip Resistance Load Test	Values in Table 10.5.5.2.2-2, but no greater than 0.70
Block Failure, ϕ_{bl}	Clay	0.60
Uplift Resistance of Single Micropile, ϕ_{up}	Presumptive Values	0.55[(1)]
	Load Test (Type A micropile) Load Test (Types B, C, D & E micropiles)	0.60 Values in Table 10.5.5.2.2-2, but no greater than 0.70
Group Uplift Resistance, ϕ_{ug}	Sand & Clay	0.50

DRAFT



AASHTO LRFD Design

Table 10.5.5.2.4-1 - Resistance Factors for Geotechnical Resistance of Axially Loaded Micropiles

METHOD/SOIL/CONDITION		RESISTANCE FACTOR
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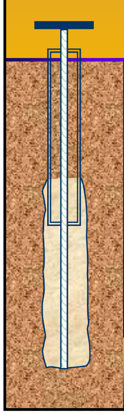
	Tip Resistance on Rock O'Neill and Reese (1999)	0.50
	Side Resistance and Tip Resistance Load Test	Values in Table 10.5.5.2.2-2, but no greater than 0.70
Block Failure, ϕ_{bl}	Clay	0.60
	Presumptive Values	0.55[1]
		Table , but no n 0.70
φ_{ug}		

- Additional reduction in resistance factors for marginal ground or lack of redundancy

DRAFT



LRFD Geotechnical Design

$$R_R = \varphi R_n = \varphi_{qp} R_p + \varphi_{qs} R_s$$

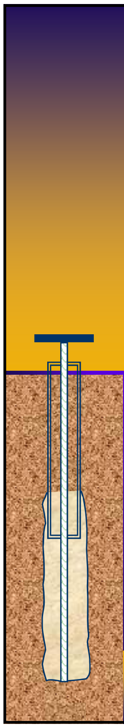
in which: (10.9.3.5.1-1)

$$R_p = q_p A_p \quad (10.9.3.5.1\text{-}2)$$

$$R_s = q_s A_s \quad (10.9.3.5.1\text{-}3)$$

where:

R_p = nominal tip resistance (KIPS)
R_s = nominal grout-to-ground bond resistance (KIPS)
φ_{qp} = resistance factor for tip resistance specified in Table 10.5.5.2.4-1
φ_{qs} = resistance factor for grout-to-bond bond resistance specified in Table 10.5.5.2.4-1
q_p = unit tip resistance (KSF)
q_s = unit grout-to-ground bond resistance (KSF)
A_p = area of micropile tip (FT^2)
A_s = area of grout-to-ground bond surface (FT^2)

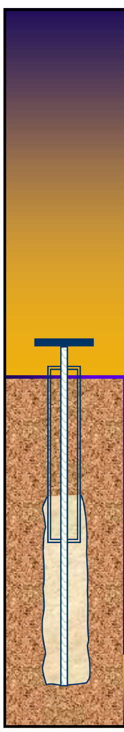


Geotechnical Design – Empirical

Average Bond Values (allowable loads)

- Clay: 15-30 kN/m (1-2 k/ft)
- Loose sands: 30-60 kN/m (2-4 k/ft)
- Compact sand: 60-120 kN/m (5-10 k/ft)
- Rock: 60-240+ kN/m (5-20+ k/ft)

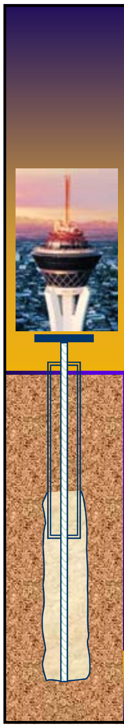
Typical for approximately 5-7 inch pile



Rock Bond Values

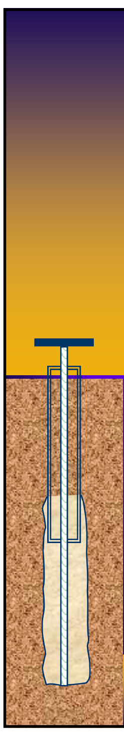
Average Rock Bond Stress (allowable)

– Shale	100-600 kPa	(15-85 psi)
– Limestone	275-1000 kPa	(40-150 psi)
– Granite/schist	300-1000 kPa	(45-150 psi)
– Basalt	1000-1400 kPa	(150-200 psi)



4. Additional Considerations

- Combined Geotechnical and Structural
  - Settlement/Stiffness of the System
  - Lateral Capacity
    - deflection
    - combined stress
    - group effect
  - Buckling



Axial Displacement

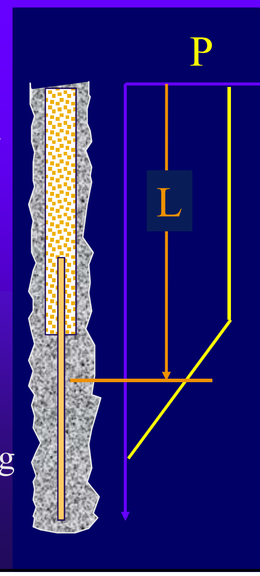
a few reminders

- Consider compatibility with existing foundation
- Elastic shortening of the pile
  - Length (elastic) is not the total length installed
- Creep – Structural not an issue, cohesive soils may be an issue
- Group Settlement

Elastic Shortening Estimate

$\Delta_{elastic} = PL / AE$

- For micropiles in competent soil, L = length above bond length plus ½ bond length
- For micropiles in rock, L = full length of micropile above bond length
- Axial stiffness, AE, considers steel and concrete if compression loading and steel only if tension loading



AE ?

$$\Delta_{elastic} = \sum_i \frac{PL_i}{AE_i}$$

$$E_{pile}A_{pile} = E_{grout}A_{grout} + E_{steel}A_{steel}$$

- **Evaluate for each section of pile**
- **E_{grout} = 1500-2500 ksi**
- **E_{steel} = 29000 ksi**

Lateral Capacity

general thoughts

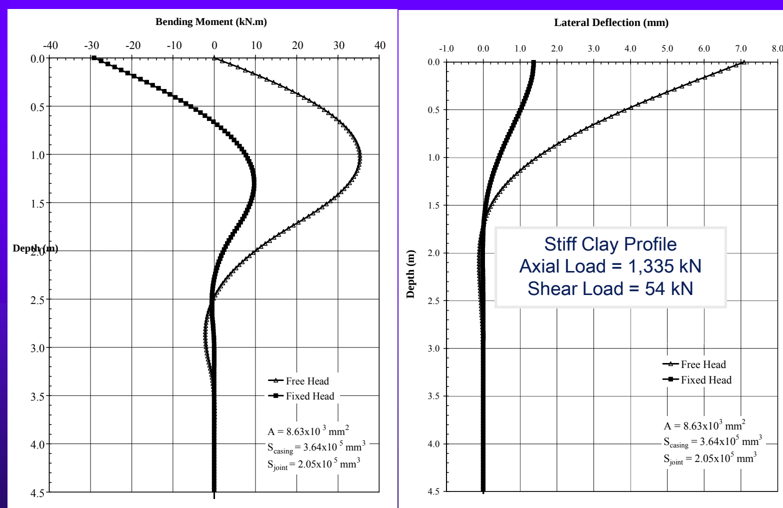
- Micropiles do not have large lateral capacities
- Design is similar to drilled shafts and driven piles
- Consider combined stress effect, particularly at the threads

Combined Axial Compression and Bending Stress

$$\frac{P_c}{P_{allowable}} + \frac{M_{max}}{M_{allowable}}$$

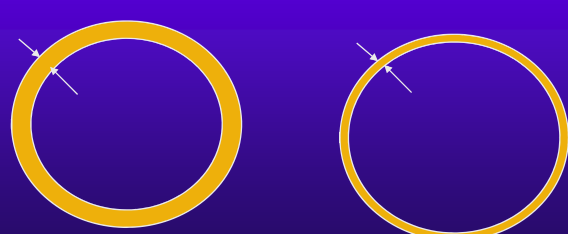
- P_c = maximum axial compression load
- $P_{c\text{-}allowable}$ = allowable compression load
- M_{max} = maximum bending moment
- $M_{allowable} = (0.55 \times F_y \times S)$

LPILE Analysis



Bending Moment Capacity at Threaded Connection

- For compression only, capacity is not affected by threaded connections
- For tension/bending, no codified testing procedure is available to evaluate strength at connection



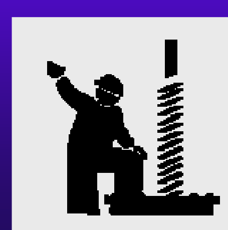
Casing with t_w Casing thread with $t_w/2$

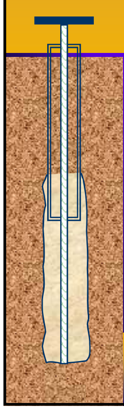
Analysis of Threaded Connection

- Use steel yield stress (no need to limit based on strain compatibility)
- Assume casing wall thickness, t_w, is reduced by 50 percent along the length of the casing joint
- Calculate section modulus of joint, S_{joint}

A Few Final Considerations

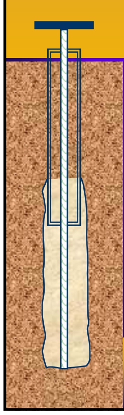
- Corrosion Protection
- Load Testing
- Quality Control Procedures
- Constructability
- Cost Effectiveness of Design





5. Design Example

- FHWA Design and Construction Manual, 2005
- Micropiles for support of a bridge abutment
- Sample Problem 1, Appendix D



Design Process

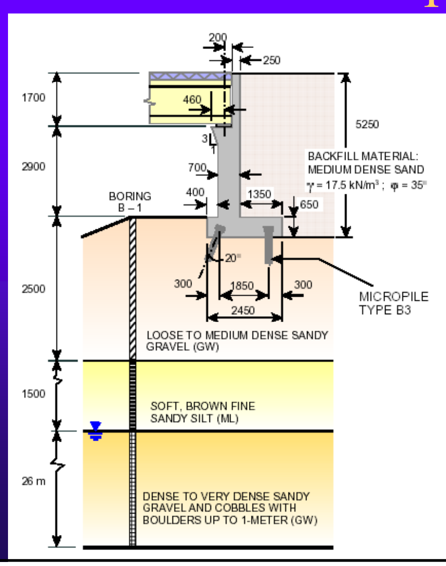
Step 1	**Evaluate Feasibility of Micropiles**
Step 2	**Review Project Information**
Step 3	**Establish Load and Performance Requirements**
Step 4	**Preliminary Design Considerations**
Step 5	**Evaluate Structural Capacity of Cased Length**

Design Process

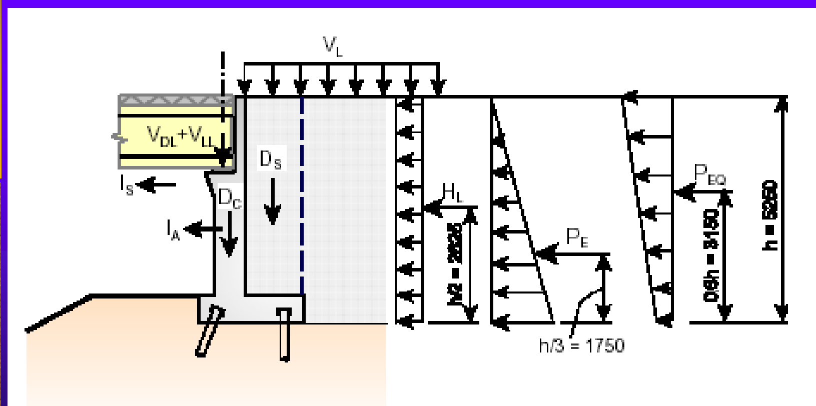
Step 6	**Evaluate Structural Capacity of Uncased Length**
Step 7	**Compare Capacity to Need**
Step 8	**Evaluate Geotechnical Capacity of Micropile**
Step 9	**Estimate Micropile Movements**
Step 10	**Design Micropile/Footing Connection**
Step 11	**Develop Load Testing Program**
Step 12	**Drawings and Specifications**

Design Example – Service Load Design Method

Overview Step 1 and 2



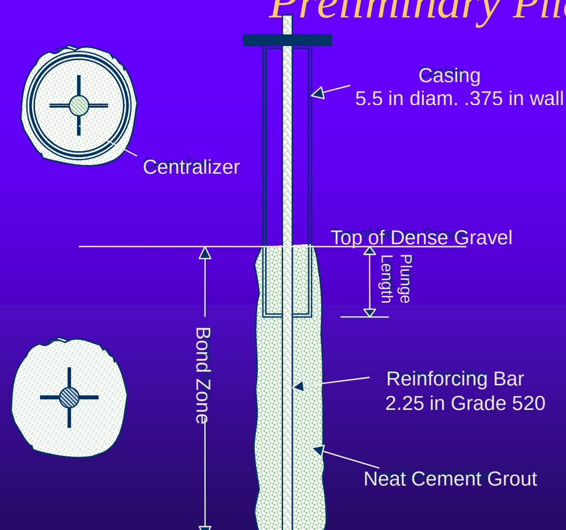
Bridge Abutment Loading Step 3



30 m long single span, AASHTO Type IV precast – prestressed concrete girders with concrete deck.

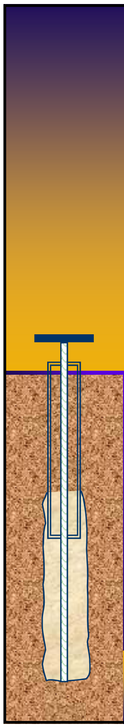
Design Example - Step 4

Preliminary Pile Detail



Case 1

Type B



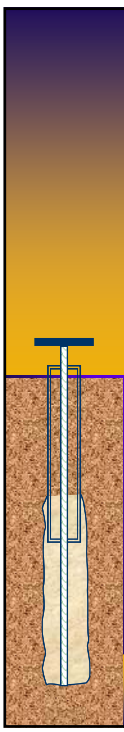
Design Example

Design Parameters

- Required Compression Load

  133 kip (assume vertical)
- Casing fy – 36 ksi
- Bar fy – 75 ksi*

  * limit fy bar to 36 ksi for Strain Compatibility
- Grout f'c – 5 ksi
- Abutment Concrete f'c – 4 ksi



Design Example

Geometry

- Reduce Steel Casing Thickness by 16th in.

  Old Manual Section 4.D.3 - 50 yr design, barely aggressive
- Casing OD =

  5.5 in – 2 x 1/16 in = 5.375 in
- Casing ID =

  5.5 in – 2 x 3/8 in = 4.8 in
- Casing Area = 5 in^2

Design Example

Geometry

- Bar Area = 2.25 in^2
- Grout Area
  - Cased Length Area = ID - Bar = 15.9 in^2
  - Uncased Zone

    Drill Diameter = 5.5 in + ~2 in = 7.5 in

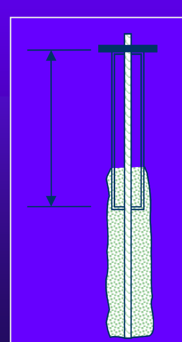
    Area = Drill - Bar = 42 in^2

Design Example – Step 5

Structural Capacity - Cased Length

$P_{c\text{-}all}=[0.4f_c'A_g+0.47F_{y\text{-}steel}(A_{bar}+A_{casing})]$

$P_{c\text{-}all}$ =151 kip



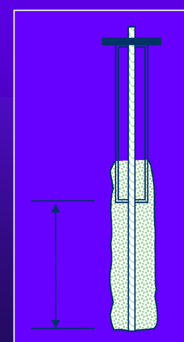
Design Example - Step 6

Structural Capacity – Uncased Zone

$P_{c\text{-}all} = 0.4f_c'A_g + 0.47F_{y\text{-}steel}A_{bar} + P_{Transfer}$

Assume $P_{Transfer} = 11$ kip

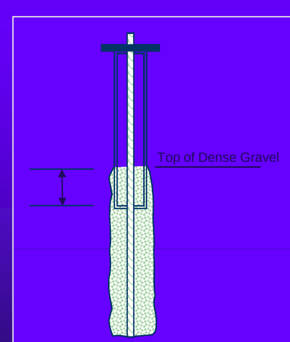
$P_{c\text{-}all} = 175$ kip

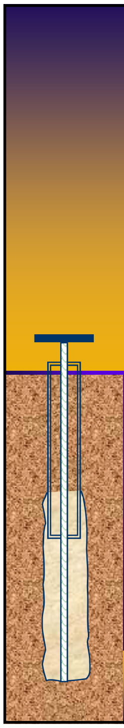


Design Example

P Transfer - Plunge Length

- Reduction of load over the length of the casing "Plunged" back into the grouted bond zone material.
- Resulting required structural capacity in bond zone is therefore reduced.



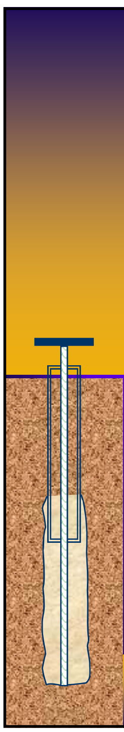


Design Example – Step 7

Comparison

- Cased Length Structural Capacity = 151 kip
- Uncased Length Structural Capacity = 175 kip
- Geotechnical Bond Capacity = ?

- Required = 134 kip So far OK!



Design Example – Step 8

Geotechnical Capacity - Uncased Zone

- Type B pile - Pressure through casing
- Very Dense Gravel w/ Cobbles
- Table 5-3
  - PTI Rock and Soil Anchors - 1996
  - Ostermayer, Construction, Carrying Behavior and Creep Characteristics of Ground Anchors - 1975
  - Xanthakos et al., Ground Control and Improvement - 1994
  - FHWA Micropile State of Practice Review - 1996
  - FHWA Tiebacks - 1982, Anchors - 1968
  - FHWA Drilled Shafts - 1988

Reference
page 5-21

Design Example

Geotechnical Capacity - Bond Values

Table 5.3

Soil/Rock Description	Typical Grout to Ground Bond Strength (kPa)			
	Type A	Type B	Type C	Type D
soft Silt and Clay some Sand	35-70 5-10 psi	35-90	50-120	50-145
Sand, some Silt med-very dense	95-215	120-360	145-360	145-385
Gravel med-very dense	95-265	120-360 17-52 psi	145-360	145-380
Soft Shale	205-550	N/A	N/A	N/A
Limestone Fresh hard	520-1725 75-250 psi	N/A	N/A	N/A

Design Example

Geotechnical Capacity - Uncased Zone

α_{bond}= 48 psi

$$P_{G\text{-}all} = \frac{\alpha_{bond}}{FS} * 3.14 * d_{bond} * L$$

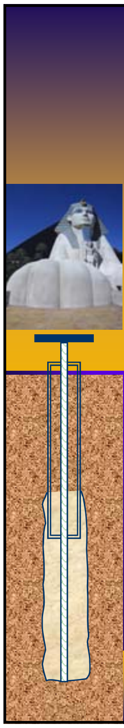
FS=2.5 Design Load = 134 kip L = 24 ft

Use L=<u>25 ft</u> $P_{G\text{-}all}$ = 135 kip

Note: this is a preliminary length, final length is dependant on the contractors methods and field testing to confirm capacities

Design Example

Summary

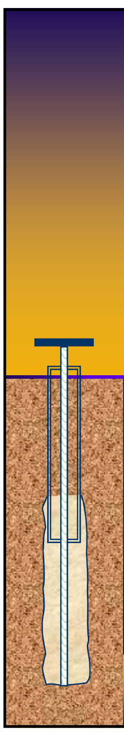


- Cased Length Structural Capacity = 151 kip
- Uncased Length Structural Capacity = 175 kip
- Geotechnical Bond Capacity = 135 kip

- Required = 134 kip OK!

Design Example

Summary



- Need minimum 25 ft uncased length
- Final length to be confirmed or modified by the testing program
- Pile performance requirement should be clearly stated in the contract and tied back to the contractors installation methods.

Design Example – Step 9

Elastic Shortening

$$\text{Shortening} = \frac{PL}{AE}$$

For Compression

AE= [Ag*Eg] + [As*Es]

L - above bond zone = 15 ft

Elastic Shortening = 0.1in

(L includes transition length)

Design Example

Settlement

- Minimum Settlement = Elastic Shortening
- Actual Settlement = Elastic Shortening + Geotechnical Settlement (permanent)
- Geotechnical Settlement Calculated Like Typical Friction Pile
- Consider Group Effects if there is tight pile spacing

Design Example – Step 10

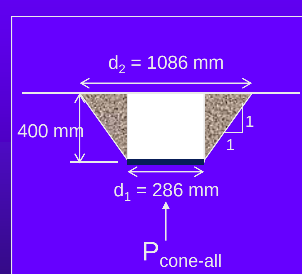
Connection Details

- New Pile Cap
- Existing Structures

Design Example

Connection - New Pile Cap

- Assuming 254 mm Square Bearing Plate
- Plate Area = 64,516 mm^2
- Equivalent Diameter = 286 mm
- $P_{cone\text{-}all} = \dfrac{4\,(f_c')^{1/2}\,Acp}{FS}$



FS = 2.35 A_{cp} = 862,053 mm^2

$P_{conc\text{-}all}$ = 640 kN > 595 kN OK!

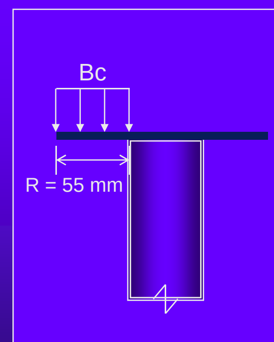
Design Example

Connection - New Pile Cap

- Plate Thickness

  Bearing Compression

  $$B_c = \frac{P_{c\text{-service}}}{A_{plate}} = 9.22 \text{ MPa}$$



$M_{max} = Bc * R^2 * 0.5 = 0.147$ kNm

$F_{y\text{-plate}} = 345$ MPa

$t_{req} = (6 * M_{max} / 0.55 F_{y\text{-plate}})^{1/2} = 21.6$ mm

Use 25 mm Thick Plate

Industrial Facility Connections

Hewlett Packard *"Corvallis, OR."*
Seismic Upgrade Connection

Screw Top Connections

Design Example

Connection - Existing Structures

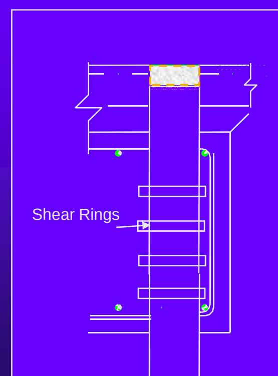
- Assuming Shear Rings 24.5 mm Wide and 12 mm Thick
- Ring Area(A_R) = 3871 mm^2
- Minimum Shear Ring Spacing

  $S_R = 4 (W_R) + t_R = 114.3$ mm
- Number of Shear Rings

  $$N_R = \frac{P_{c\text{-service}} * LF}{A_R*2*f*0.85f_c'}$$

  f = 0.7 LF = 1.53

  $N_R = 2.11$ Use 3 Shear Rings



Reference page 5-37

Design Example – Step 11 Load Test

- Required Load

  Verification 2.5 x Design Load = 337 kip
- Structural Capacity - Casing

  Pc-all = [0.68fc'Ag+0.8Fy-steel(Abar+Acasing)]

  Pc-all = 287 kip

- Casing not reduced for corrosion

Design Example

Load Test

Structural Capacity - Bond Zone

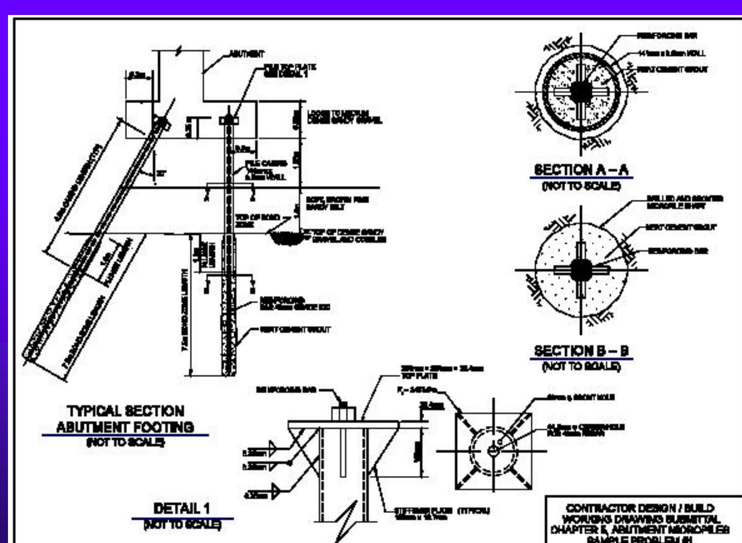
$P_{c\text{-}all} = 0.68 f_c' A_g + 0.8 F_{y\text{-}steel} A_{bar} + P_{Trans\ All}$

$P_{Trans\ All} = \dfrac{\alpha * 3.14 * d * PL}{1.25} = 36 \text{ kip}$

$P_{c\text{-}all} = 315 \text{ kip} < 337 \text{ kip}$

Pile not suitable for verification load test increase casing thickness and bar diameter

Final Drawings - Step 12



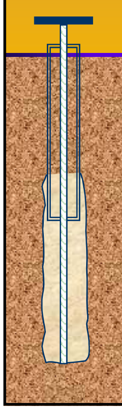
Reference page 5-104

Specifications

- Private Projects
  - DFI/ADSC Guide Spec
  - IBC 2006
- Public Work
  - FHWA Manual
  - AASHTO (2008 interim)
- International
  - JAMP
  - Eurocode

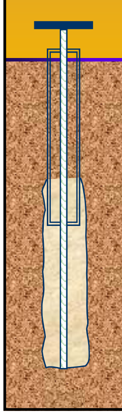
Summary

- Understanding goals and constraints
- Know the available tools
- Engineering design
- Construction verification



Summary

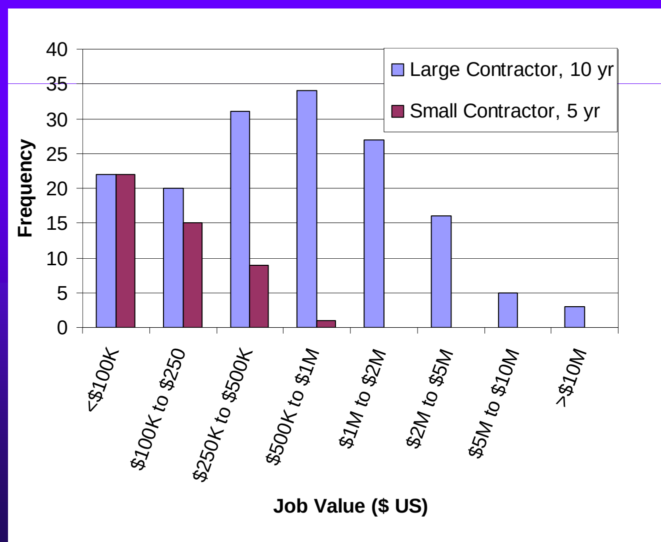
- Most effective designs are tailored to the contractor doing the installation
- Field verification and experience are imperative to success



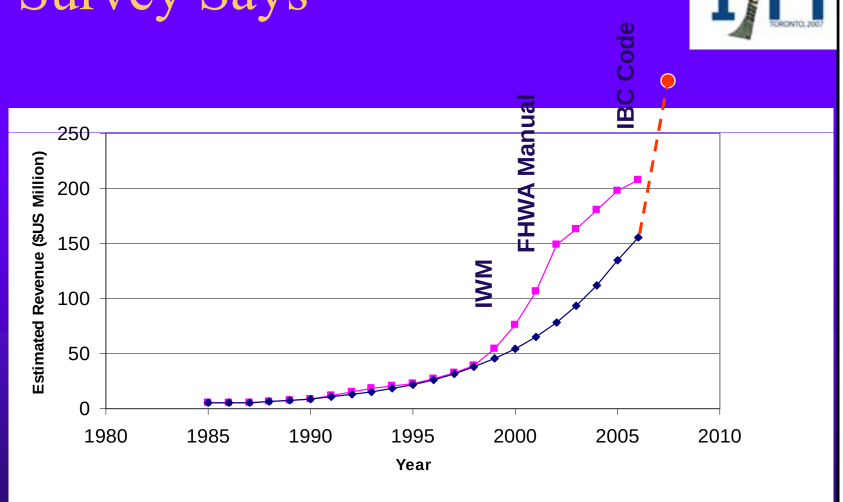
Summary

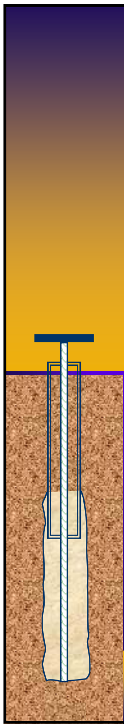
"Problems may occur if the designer lacks the expertise in micropile design and construction techniques or lacks the control of construction on site to avoid methods that may be detrimental to the pile's capacity" (FHWA 2000)

Project Sizes



Survey Says





Thank You!

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