Lecture 1 – Introduction to Deep Foundations

Class Notes
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OVERVIEW

- Introduction
- Usage
- Historical Perspective
- Classification
- Design Process
- Economics
INTRODUCTION – Definition

- PILE
  
  (1) A structural member that is used to transmit surface loads to lower elevations in the soil.

  (2) Piles are common foundation tools for transferring superstructure through water and/or soft soil deposits. The loads may be distributed through the soils (friction piles) or transferred to firm, underlying soil or rock strata (end bearing piles). Most piles function as a combination of the two.

INTRODUCTION – Definition

- The element of a structure that transfers loads to the underlying ground with performance consistent with the design of the structure.

- Loads are a combination of:
  - Static
  - Dynamic
  - Horizontal
  - Vertical
INTRODUCTION

- **Main Problem**
  Limited ability to accurately assess the capacity and integrity state of a pile in the ground. Required to allow safe and optimal design and construction.

- **History**
  **General**
  Man’s oldest method of overcoming the difficulties of founding above water and/or on soft soils. The Neolithic inhabitants of Switzerland supported their homes 12,000 years ago on driven wooden poles in shallow lakes. The ancient Egyptians depicted manpower pile driving operations and failures. The Romans supported many of their bridges over the Rhine river with driven timber piles.
  Modern analysis and literature began at the end of the 19th century.
  Diesel hammers were used after the second World War.

Performance

Some work better than others.
Performance

Transcona Grain Elevator
Winnipeg, Manitoba
October 18, 1913
Tilt: 27°
Photograph and Figure from Baracos (1957).

Bridge Abutment on Piles - 30 inches of Settlement over 10 years
Photograph courtesy of FHWA-NHI-132012 Soils and Foundations Workshop Participants Workbook

Performance

Lee Roy Selmon Expressway, Tampa, FL

• Drilled Shafts sink 11ft
• Repair Cost: $92,000,000
• 155 of 224 Shafts Strengthened

Source: Tampa Bay Times

What caused the collapse
A combination of unstable soil and excessive weight from the expressway caused one portion of the expressway to collapse, officials say.

Photograph: St. Petersburg Times

Infographic: St. Petersburg Times
Use of Deep Foundations

(a) Upper Strata Weak or Compressible
(b) Uplift
(c) Lateral Loading

Vesić (1977)
Use of Deep Foundations

(d) Combined Uplift and Lateral Loading
(e) Scour
(f) Liquefaction

Bridge Bent
Highway Signs Or Noise Barriers

Vesić (1977)

(g) Fender Systems
(h) Underpinning
(i) Swelling Soils

Future Excavation

Swelling Soil
Stable Soil

Vesić (1977)
Example – Scour

Bridge Abutment Scour
Photograph courtesy of FHWA-NHI-132012 Soils and Foundations Workshop Participants Workbook

Example – Scour

Scour at Bridge Abutment
Photograph courtesy of FHWA-NHI-132012 Soils and Foundations Workshop Participants Workbook
Drilled foundations are a relatively new technique. Pile driving, however, dates back many centuries. Herodotus, the fourth century BC Greek writer ("the father of history"), provides historical documented references to piles. Ancient Egyptians depicted hieroglyphics of pile driving. Romans, Chinese, Mesopotamians and others used driven piles.
Hammer aka Pile Driver – a mechanical device used to drive piles into soil

Historical pile hammers include a heavy weight placed between guides so that it is able to freely slide up and down vertically or inclined. The hammer is placed upon a pile and the weight is raised -- an operation which may involve the use of manual labor, steam, air, diesel, or hydraulic power. The weight is then released and impacts the pile in order to drive it into the ground.

There is evidence that a pile driving device was used in the construction of Crannogs (artificial islands) at Oakbank and Loch Tay in Scotland as early as 5000 years ago. (Ref - History Trails: Ancient Crannogs from BBC's Mysterious Ancestors series)

Reconstructed Crannóg on Loch Tay
Vitruvius was an architect and engineer under Julius Caesar in the first century B.C. and retired when Augustus died. Under Octavian’s patronage, he wrote a ten-volume account of known technology by the name of *De Re Architectura* (On Architecture).

“...But if a solid foundation is not found, and the site is loose earth right down, or marshy, then it is to be excavated and cleared and remade with piles of alder or of olive or charred oak, and the piles are to be driven close together by machinery, and the intervals between are to be filled with charcoal. Then the foundations are to be filled with very solid structures.”

Ivo Herle, Institute of Geotechnical Engineering, TU Dresden, Germany, 2004
HISTORICAL PERSPECTIVE OF PILE DRIVING

Double timber pilings were rammed into the bottom of the river by winching up a large stone and releasing it, thereby driving the piles into the riverbed. The most upstream and downstream pilings were inclined and secured by a beam, and multiple segments of these then linked up to form the basis of the bridge.

Roman Hammer (replica) used at the construction of Caesar's Rhine bridges during the Gallic War (1st bridge 55 BC and 2nd bridge 53 BC)

Roman Bridge on the Mosel—Currently in use in Trier Germany
Porta Nigra Trier Germany

Manual Timber Pile Driving - Holland

Movie Clip: Manual Timber Pile Driving - Holland
Timber-a & Timber-b
HISTORICAL PERSPECTIVE OF PILE DRIVING

Pile Foundations of Bridges

Bridge of Beaugency (central France) (earlier than 14th century)
– foundations of a pier on sand
– masonry on short wooden piles

(Herle, 2004)

HISTORICAL PERSPECTIVE OF PILE DRIVING

Drop-Hammer Piling Rig, hand operated, designed by Francesco Di Giorgio (around 1450, credited as the first hammer design drawings)

(Herle, 2004)
HISTORICAL PERSPECTIVE OF PILE DRIVING

Rialto Bridge, Venice (1588-92)

- Single span of 26.4m (119.4ft) (designed by Antonio da Ponte)
- Alluvium subsoil
- Beneath each abutment 600 piles – 15 cm diameter, 3.3 m length (3 groups)

(Herle, 2004)

Steam Hammers

- Advanced design of steam engines had become a major source of mechanical power in the 18th century enabling the industrial revolution.

- Otis Tufts (1804 - 1869) Massachusetts USA - built the first steam-operated printing press (1837) and invented the steam pile hammer.

- For the first time pile driving was performed utilizing mechanical power produced by a machine.
THE PRINCIPLE OF MODERN PILE HAMMERS

Basic System – The Drop Weight Hammer

[Diagram of a drop weight hammer system with labels for parts such as crane, hammer, guiding frame, tested shaft, instrumentations, and data acquisition system.]
THE PRINCIPLE OF MODERN PILE HAMMERS
Basic System – The Drop Weight Hammer

Pileco of Houston. The system having swinging leads operated with a small crane.

THE PRINCIPLE OF MODERN PILE HAMMERS
Modified Drop Weight Hammer - Operation

Updated Israeli Drop Weight System (2009)
Diesel hammer – Crane initially lifts ram. Ram is released and falls; at select point fuel is injected. Ram compresses the fuel and ignites it. Resulting explosion drives pile and lifts ram for next cycle.
THE PRINCIPLE OF MODERN PILE HAMMERS

Single Acting Air/Steam Hammers

**Single Acting Hammer**
Single acting hammer. At bottom of stroke, intake opens with steam pressure raising ram. At top of lift steam is shut off and intake becomes exhaust, allowing ram to fall.

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Double Acting Air/Steam Hammers

**Double Acting Hammer**
Double acting hammer. Ram in down position trips S2, which opens inlet and closes exhaust valves at B and shuts inlet and opens exhaust at A; hammer then raises from steam pressure at B. Ram in up position trips S2, which shuts inlet B and opens exhaust; valve A exhaust closes; steam enters and accelerates ram downward.
THE PRINCIPLE OF MODERN PILE HAMMERS
Single and Double Acting Hydraulic Hammers

Schematics of Single and Double Acting Hydraulic Hammers (FHWA)

IHC S-600 Hydraulic Hammer: Rated Energy ~440kip-ft (600kN-m)
Different Deep Foundations Classifications

(1) **Methods of construction:**
- driven piles
- cast in place piles
- vibrated piles
- jacked piles

Broadly categorized as Driven Piles and Drilled Foundations or In-Place Constructed Deep Foundations (IPCDF)

(2) **Pile type by material:**
- timber
- steel
- concrete

(3) **By their influence zone:**
- small displacement vs.
- large displacement piles

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**Deep Foundation Classifications**

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Figure 8.1. FHWA HI-97-013 Driven Pile Design and Construction Volume I.
Deep Foundation Classifications

Figure 8.1. FHWA NHI-05-042 Design and Construction of Driven Pile Foundations Volume I.

Use of Foundations in Bridge Construction

(1) **NCHRP 507 Report:**
- Survey in 2000 as part of NCHRP research
  - 75% Driven Piles  
  - 14% Shallow Fnds.  
  - 11% DS

(2) **NCHRP 12-66:**
- Summer 2004 Survey
  - 62% Driven Piles  
  - 17% Shallow Fnds.  
  - 21% DS

Conclusions:
- Reduced use of DP
- Yet 3 times the use of IPCDF

(3) **2000 Study:**
- DP
  - 21% PPC
  - 52% H
  - 2% OEP
  - 25% CEP

**IPCDF ⇒ DS no use of CFA (?)**

14.528 Drilled Deep Foundations – Samuel Paikowsky
Drilled Shafts: History

- Development progressed by and large independently worldwide.

- Different names are therefore associated with different construction methods or different geographical zones. All the names relate essentially to deep foundation elements constructed in place, differing from the prefabricated piles used in driving.
Drilled Shafts: History

vocabulary:
- Caissons ("Old Timers", Midwestern US)
- Cast in Drilled Hole Pile (California by Caltrans)
- Drilled Piers (NCDOT, Midwestern US)
- (Drilled) Shafts (Texas)
- Bored Piles (outside the US)
- Rock Sockets

CAISSONS: Very large footings which are sunk into position by excavation through or beneath the caisson structure. Used for hundreds of years.

Notable Examples:
- Firth of Forth Bridge (Scotland)
- Brooklyn Bridge (1870's)
- Eads Bridge (1870's)

Pneumatic Caisson, Firth of Forth Bridge (Mackay, 1990)
Motivated by large building construction in cities such as Chicago, Detroit, Cleveland and London with a subsurface consisting of thick layers of clay overlying a glacial till or bedrock.

- Late 1800, hand dug “Chicago” and “Gow” caissons were excavated to a hardpan layer to act like a deep footing. Sections of permanent liners were placed to retain the soil. Usually very conservative design of about 380kPa (4tsf).
Drilled Shafts: History

• 1908 – Early power driven auger, 0.3m diameter to a depth of 6 to 12m.
• 1920 – Horse – driven rotary machines in Texas (swelling conditions).
• 1931 – Hough Williams of Dallas built small machines for shallow hole excavation followed by truck mounted machines.
• 1932 – A.H. Beck Company (Texas) begins constructing drilled shafts.

Drilled Shafts: History

• 1937 - McKinney Drilling founded in Texas.
• Before WW II – development of large scale, mobile, auger-type, earth-drilling equipment allowing for a more economical and faster construction of drilled shafts.
• Late 1940’s and 1950’s – techniques for larger underreams, cutting in rock, casing and drilled mud (a process established by the oil industry).
Drilled Shafts: History

• 1960’s to Today - The development of theories for design and analytical techniques lagged behind the developments in the construction methods. The marked differences between driven piles and drilled shafts as well as the importance of quality control and inspection were realized.

Drilled Shafts

Terminology

- Barrette Foundations
- Different shaped cast in place elements (e.g., rectangle, round, H, etc.) usually associated with slurry wall construction.
- Other types of constructed in place deep foundations. Geojet, soil-cement mix, mini or micro-piles, pin-piles and more are available but are not drilled shafts.
- PIF (Pressure Injected Footings) are also concrete constructed in place deep foundations but due to the construction method, they also are not considered drilled shafts.
DRILLED DEEP FOUNDATIONS
Dry and Slurry Methods of Construction

Drilling to full depth (bucket or flight auger) with Slurry
DRILLED DEEP FOUNDATIONS
Slurry Method of Construction

Placing the Rebar Cage

Placing Concrete using Tremy
DRILLED DEEP FOUNDATIONS
Slurry Method of Construction

Completed Shaft

Deep Foundation Examples:
Drilled Shafts

Town Creek  West Tower

Arthur Ravenel Jr. Bridge
Photograph courtesy of WPC Inc. and Marvin Tallent, Palmetto Bridge Constructors
DRILLED DEEP FOUNDATIONS
Continuous Flight Auger (CFA) Construction

Cast in Place Concrete Piles
(Mandrel Driven)

<table>
<thead>
<tr>
<th>Design Capacity Range</th>
<th>50 to 120 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Range</td>
<td>Up to 100 ft (check manufacturer)</td>
</tr>
<tr>
<td>Application</td>
<td>Friction or Bearing</td>
</tr>
<tr>
<td>Typical Building Code Allowable Stresses</td>
<td>$f_c \leq 33% f'c$ ($f_c \leq 1600$ psi)</td>
</tr>
<tr>
<td>Pile Deterioration</td>
<td>High sulfate soils or groundwater, exposure to freeze/thaw may require special concrete mix.</td>
</tr>
<tr>
<td>Applicable Material Specifications</td>
<td>ACI-318-2011 &quot;Building Code Requirement for Structural Concrete and Commentary ACI 543R-00</td>
</tr>
</tbody>
</table>

Design Considerations:
1. Corrugated metal shell piles (Raymond, Guild, etc.) may be used as friction or bearing piles. Smooth steel piles (pipe, monotube, etc.) usually not as efficient as friction piles.
2. Must be able to predict maximum length for mandrel driven piles since splicing is not possible.
3. Shells susceptible to collapse after driving and prior to concreting.
4. Piles can be inspected internally after driving.
5. Mandrel increases driveability considerably.
6. Reinforcement must be added for lateral and uplift loads.

See NHI publication Table 8-1, p.8-7
Cast in Place Concrete Piles

Cast in Place Concrete Piles
Deep Foundations: Cast-In-Place (CIP) Piles

Table 8-1. FHWA NHI-05-042 (from NAVFAC DM7.02).

<table>
<thead>
<tr>
<th>PILE TYPE</th>
<th>CAST-IN-PLACE CONCRETE</th>
<th>TYPICAL ILLUSTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPICAL LENGTHS</td>
<td>5 m - 25 m (16 - 80 ft)</td>
<td></td>
</tr>
<tr>
<td>MATERIAL SPECIFICATIONS</td>
<td>ACI 318 - for concrete, ASTM A252 - for steel pipe.</td>
<td></td>
</tr>
<tr>
<td>MAXIMUM STRESSES</td>
<td>See Chapter 10.</td>
<td></td>
</tr>
<tr>
<td>TYPICAL AXIAL DESIGN LOADS</td>
<td>500 kN - 1350 kN (110 - 300 kips)</td>
<td></td>
</tr>
<tr>
<td>DISADVANTAGES</td>
<td>• Difficult to splice after concreting.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Considerable displacement.</td>
<td></td>
</tr>
<tr>
<td>ADVANTAGES</td>
<td>• Can be re-driven.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Shell not easily damaged if fluted.</td>
<td></td>
</tr>
<tr>
<td>REMARKS</td>
<td>Best suited for friction piles of medium length.</td>
<td></td>
</tr>
</tbody>
</table>
### Deep Foundations: Composite Piles

**Table 8-1. FHWA NHI-05-042 (from NAVFAC DM7.02).**

<table>
<thead>
<tr>
<th>PILE TYPE</th>
<th>COMPOSITE PILES</th>
<th>TYPICAL ILLUSTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPICAL LENGTHS</td>
<td>15 m - 65 m (50 – 210 ft)</td>
<td></td>
</tr>
<tr>
<td>MAXIMUM STRESSES</td>
<td>33% of 28-day strength of concrete. 65 MPa (9 ksi) for structural and pipe sections if thickness is greater than 4 mm (0.16 inches).</td>
<td></td>
</tr>
<tr>
<td>TYPICAL AXIAL DESIGN LOADS</td>
<td>300 kN - 1,800 kN (70 – 400 kips)</td>
<td></td>
</tr>
<tr>
<td>DISADVANTAGES</td>
<td>• Difficult to attain good joints between two materials except for concrete H or pipe composite piles.</td>
<td></td>
</tr>
<tr>
<td>ADVANTAGES</td>
<td>• Considerable length can be provided at comparatively low cost for wood composite piles. • High capacity for some composite piles. • Internal inspection for pipe composite piles.</td>
<td></td>
</tr>
<tr>
<td>REMARKS</td>
<td>• The weakest of any material used shall govern allowable stresses and capacity.</td>
<td></td>
</tr>
</tbody>
</table>

### Cast in Place (Uncased) Piles (Drilled Shafts Caissons)

- **Design Capacity Range**: Up to 1000’s tons
- **Length Range**: Up to 100’s ft
- **Application**: Friction or Bearing
- **Typical Building Code Allowable Stresses**: $f_c \leq 33\% f'_c$, $f_c \leq 1600$ PSI
- **Pile Deterioration**: High sulfate soils or groundwater, exposure to freeze/thaw may require special concrete mix.
- **Applicable Material Specifications**: ACI-318-2011 “Building Code Requirement for Structural Concrete and Commentary

**Design Considerations:**
1. Not suitable for use through peat or similar very soft soils.
2. Continuity of shaft cannot be verified.
3. No driving vibrations.
4. Completely nondisplacement (except interpile).

See NHI publication Table 8-1, p.8-11

14.526 Drilled Deep Foundations - Samuel Palkowsky
Cast in Place (Uncased) Piles
(caissons)

Cast in Place (Uncased) Piles
Cambridge Water Treatment Facilities
Deep Foundations: Cast-In-Place (CIP) Piles

Table 8-1. FHWA NHI-05-042 (from NAVFAC DM7.02).

<table>
<thead>
<tr>
<th>PILE TYPE</th>
<th>TYPICAL PLACED, PRESSURE INJECTED CONCRETE PILES (CFA PILES)</th>
<th>TYPICAL ILLUSTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPICAL LENGTHS</td>
<td>6 m - 26 m (15 – 80 ft)</td>
<td></td>
</tr>
<tr>
<td>MAXIMUM STRESSES</td>
<td>33% of 28-day strength of concrete.</td>
<td></td>
</tr>
<tr>
<td>TYPICAL AXIAL DESIGN LOADS</td>
<td>260 kN - 875 kN (60 – 200 kips)</td>
<td></td>
</tr>
<tr>
<td>DISADVANTAGES</td>
<td>Greater dependence on quality workmanship.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Not suitable through peat or similar highly compressible material.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Requires more extensive subsurface exploration.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>No driving observation (below count) to aid in assessing capacity.</td>
<td></td>
</tr>
<tr>
<td>ADVANTAGES</td>
<td>Economy.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Zero displacement.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Minimal vibration to endanger adjacent structures.</td>
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<tr>
<td></td>
<td>High shaft resistance.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good contact on rock for end bearing.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Visual inspection of augured material.</td>
<td></td>
</tr>
<tr>
<td>REMARKS</td>
<td>Best suited as a friction pile in granular material.</td>
<td></td>
</tr>
</tbody>
</table>

ACIP – Auger Cast In Place DD – Drilled Displacement
CFA – Continuous Flight Auger APG - Auger Pressure Grouted
APGD - Auger Pressure Grouted Displacement

Deep Foundation Examples: Cast-In-Place (CIP) Piles

Static Load Test on DD Pile
Photograph courtesy of WPC Inc.

CFA Rig
Photograph courtesy of www.skanska.co.uk
The Continuous Flight Auger (CFA) Construction Sequence is comprised of four stages:

1. The digging head of the auger is fitted with an expendable cap.
2. The auger is screwed into the ground to the required depth.
3. Concrete is pumped through the hollow stem, blowing off the expendable cap under pressure, and
4. Maintaining positive concrete pressure the auger is withdrawn and the reinforcement is placed into the pile up to the required depth.
## Deep Foundations: Drilled Shafts

Table 8-1. FHWA NHI-05-042 (from NAVFAC DM7.02).

<table>
<thead>
<tr>
<th>PILE TYPE</th>
<th>DRILLED SHAFTS</th>
<th>TYPICAL ILLUSTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPICAL LENGTHS</td>
<td>5 m to 95 m or more (15 – 300 ft)</td>
<td></td>
</tr>
<tr>
<td>MATERIAL SPECIFICATIONS</td>
<td>ACI 318 - for concrete, ASTM A325, A615, A722, and A834 for reinforcing steel</td>
<td></td>
</tr>
<tr>
<td>MAXIMUM STRESSES</td>
<td>33% of 20-day strength of concrete.</td>
<td></td>
</tr>
<tr>
<td>TYPICAL AXIAL DESIGN LOADS</td>
<td>1,000 kN - 20,000 kN (220,000 – 4,500 kips) or more.</td>
<td></td>
</tr>
<tr>
<td>DISADVANTAGES</td>
<td>• Requires relatively more extensive inspection. • Construction procedures are critical to quality. • Boulders can be a serious problem, especially in small diameter shafts. • Mobilization of end bearing on a long shaft can require substantial displacement of shaft head.</td>
<td></td>
</tr>
<tr>
<td>ADVANTAGES</td>
<td>• Length variations easily accommodated. • High bearing capacity and bending resistance. • Availability of several construction methods. • Can be continued above ground as a column.</td>
<td></td>
</tr>
<tr>
<td>REMARKS</td>
<td>• No drilling observations (drill count) available to aid in assessing capacity. • Not recommended in soft clay and loose earth.</td>
<td></td>
</tr>
</tbody>
</table>

## Deep Foundations: Micropiles (a.k.a. Mini, Pin)

Table 8-1. FHWA NHI-05-042 (from NAVFAC DM7.02).

<table>
<thead>
<tr>
<th>PILE TYPE</th>
<th>MICROPILES</th>
<th>TYPICAL ILLUSTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPICAL LENGTHS</td>
<td>12 m - 25 m (40 – 100 ft)</td>
<td></td>
</tr>
<tr>
<td>TYPICAL AXIAL DESIGN LOADS</td>
<td>300 kN - 1100 kN (70 – 250 kips)</td>
<td></td>
</tr>
<tr>
<td>DISADVANTAGES</td>
<td>• Cost</td>
<td></td>
</tr>
<tr>
<td>ADVANTAGES</td>
<td>• Low noise and vibrations. • Small amount of spoil. • Excellent for sites with low headroom and restricted access. • Applicability to soil containing rubble and boulders, kenny areas.</td>
<td></td>
</tr>
<tr>
<td>REMARKS</td>
<td>• Can be used for any soil, rock or fill condition.</td>
<td></td>
</tr>
</tbody>
</table>
Micropiles: History

- Early 1950’s in Italy – Conceived to underpin historic structures and monuments damaged in WW II.
- 1952 - Palo Radice (Root Pile) patented by Fondedile (Dr. Fernando Lizzi).

From FHWA SA-97-020, Bruce (2008), and Bennett (2010)

Micropiles: History

- 1970 – Fondedile Corp. established in US.
- 1980 to 90 – Decline and Closure of Fondedile in US.
- Early 1980’s - Big “Push” by East Coast Contractors.

From FHWA SA-97-020, Bruce (2008), and Bennett (2010)
Micropiles: History

• 1989 – Loma Prieta & Start of Micropile Seismic Retrofits on West Coast.


From FHWA SA-97-020, Bruce (2008), and Bennett (2010)

Micropile Seismic Retrofit (Photograph courtesy of Palmetto Gunite)

[Image]

Micropiles: History

• 1996 to 1999 – FHWA Implementation Manual

• 1997 – International Workshop on Micropiles (IWM) Founded

• 2002 – ADSC develops FHWA/NHI Course

• 2005 – International Society of Micropiles (ISM) Founded

From FHWA SA-97-020, Bruce (2008), and Bennett (2010)

Micropile Seismic Retrofit (Photograph courtesy of Palmetto Gunite)
Deep Foundation Examples: Micropiles

Static Load Test
50 Broad St., Charleston, SC
Hajduk et al. (2004)

Dynamic Load Test
Photographs courtesy of WPC Inc.

Deep Foundations: Pressure Injected Footing

Table 8-1. FHWA NHI-05-042 (from NAVFAC DM7.02).

<table>
<thead>
<tr>
<th>PILE TYPE</th>
<th>PRESSURE INJECTED FOOTINGS</th>
<th>TYPICAL ILLUSTRATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPICAL LENGTHS</td>
<td>3 m - 15 m (10 – 50 ft)</td>
<td></td>
</tr>
<tr>
<td>MATERIAL SPECIFICATIONS</td>
<td>ACI 318 - for concrete</td>
<td>ASTM A532 for steel pipe.</td>
</tr>
<tr>
<td>MAXIMUM STRESSES</td>
<td>33% of 28-day strength of concrete. 62 MPa (9 ksi) for pipe shell if thickness is greater than 4 mm (0.16 inches)</td>
<td></td>
</tr>
<tr>
<td>TYPICAL AXIAL DESIGN LOADS</td>
<td>600 kN - 1,200 kN (135 – 270 kips)</td>
<td></td>
</tr>
<tr>
<td>DISADVANTAGES</td>
<td>Base of footing cannot be made in clay or when hard spots (e.g., rock loddges) are present in soil. When clay layers must be penetrated to reach suitable material, special precautions are required for shafts in groups.</td>
<td></td>
</tr>
<tr>
<td>ADVANTAGES</td>
<td>Provides means for placing high capacity footings on bearing stratum without necessity for excavation or desaturation. High blow energy available for overcoming obstructions. Great uplift resistance if suitably reinforced.</td>
<td></td>
</tr>
<tr>
<td>REMarks</td>
<td>Steel suited for granular soils where bearing is achieved through compaction around base. Minimum spacing 1.5 m (5 ft) on center.</td>
<td></td>
</tr>
</tbody>
</table>

PIF – Pressure Injected Footings; a.k.a. Franki Piles
### Compacted Concrete Piles  
**(Pressure Injected Footing, PIF) (FRANKI piles)**

<table>
<thead>
<tr>
<th><strong>Design Capacity Range</strong></th>
<th>50 to 150 tons</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length Range</strong></td>
<td>Up to 60 ft</td>
</tr>
<tr>
<td><strong>Application</strong></td>
<td>Bearing</td>
</tr>
<tr>
<td><strong>Typical Building Code Allowable Stresses</strong></td>
<td></td>
</tr>
</tbody>
</table>
  \( f_c \leq 0.33 \cdot f'_c \)  
  \( f_c \leq 1600 \text{ PSI} \) |
| **Pile Deterioration**    | High sulfate soils or groundwater, exposure to freeze/thaw may require special concrete mix. |

#### Applicable Material Specifications
- ACI-318-2011 “Building Code Requirement for Structural Concrete and Commentary

#### Design Considerations:
1. Suitable only for use as bearing piles in clean granular soils.
2. Very economical for use in sand stratum overlying thick clay stratum.
3. Designer must know depth and thickness of bearing stratum.
4. High energy drop hammer with bottom driven tube well suited to overcoming obstructions.
5. Shafts should be cased in organic soils.

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![Diagram of Compacted Concrete Piles](image-url)

See NHI publication Table 8-1, p.8-12  
14.528 Drilled Deep Foundations – Samuel Paikowsky
Deep Foundations: Pressure Injected Footing

PIF – Pressure Injected Footings; a.k.a. Franki Piles

Figure courtesy of Franki GRUNDAU.

Compacted Concrete Piles

(Pressure Injected Footing, PIF)
(FRANKI piles)
Deep Foundation Examples:

PIF

Excavated
Photograph courtesy of www.geoforum.com

LeLachuer Park, Lowell, MA
Photograph courtesy of www.peepil.com

PIF – Pressure Injected Footings; a.k.a. Franki Piles

DEEP FOUNDATION DESIGN PROCESS
Deep Foundation Design Process

DEEP FOUNDATION DESIGN PROCESS

Field Exploration & Testing

Geotechnical Strength & Deformation Parameters

Static Analysis of Deep Foundation

Dynamic Analysis of Driven Piles

Deformation and Settlement

Bearing Capacity Vertical and Lateral Resistance Single/Group

Design

Geometry
Configuration
Installation Criteria

Superstructure Loading Evaluation

Superstructure Loading Requirement

Completing Substructure

Testing
- material
- performance
- driving
- integrity

QC Monitoring

Construction

Design Verification/Modification
- dynamic testing
- static testing

Yes

No

OK

No

Yes

Axial Capacity

Where:

\[ Q_{total} = \sum Q_{skin} + Q_{tip} \]

\[ Q_{total} = \text{Ultimate Pile Capacity} \]

\[ Q_{skin} = \text{Skin Friction (i.e. Side) Capacity} \]

\[ Q_{tip} = \text{Tip (i.e. Toe) Capacity} \]
Deep Foundation Design

Axial Capacity

\[ Q_{\text{skin}} = f_s A_{\text{skin}} \]
\[ Q_{\text{toe}} = q_p A_{\text{toe}} \]

Where:
- \( f_s \) = Unit Skin Friction
- \( A_{\text{skin}} \) = Pile Skin Area

Where:
- \( q_p \) = Unit End Bearing
- \( A_{\text{toe}} \) = Pile Toe (i.e. Tip) Area

Deep Foundations:

Effects of Pile Installation