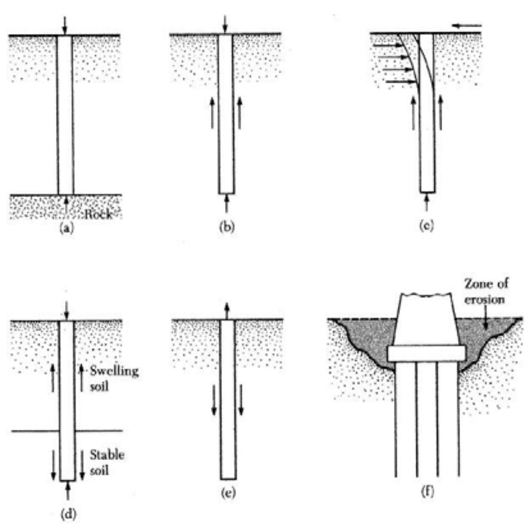
Deep Foundation

Deep Foundation Applications

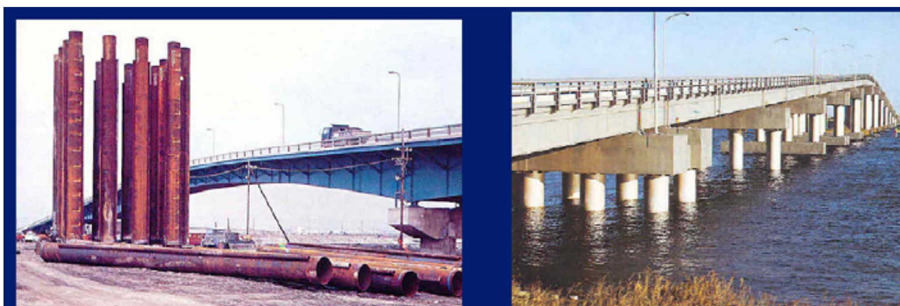


1. Soils with:
- High compression
- Low shear strength
- Swelling/shrinkage
2. Resist lateral loads
3. Surface erosion
4. Resist tension (anchors)

Typical Applications

Marine and harbour works

Typical Applications



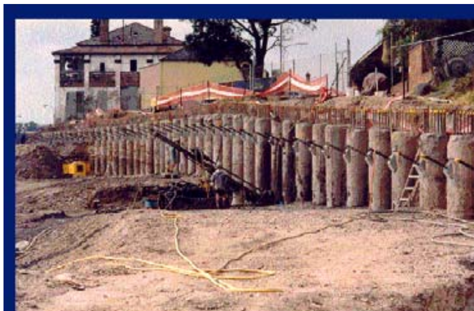
Roads & bridges

Typical Applications

Buildings

Storage Tanks

Typical Applications



Retaining Wall, Sydney

Retaining Wall, Hong Kong

Industry Outlook

Types of Piles

Classification by Material
- Steel
- Concrete
- Timber

Effect of Installation
- Displacement
- Low displacement
- Non-displacement

Method of Installation
- Driven, Driven & Cast in place
- Bored (drilled)
- Composite
- Screwed

Impact of Installation

Bored | Driven in Clay | Driven in Sand

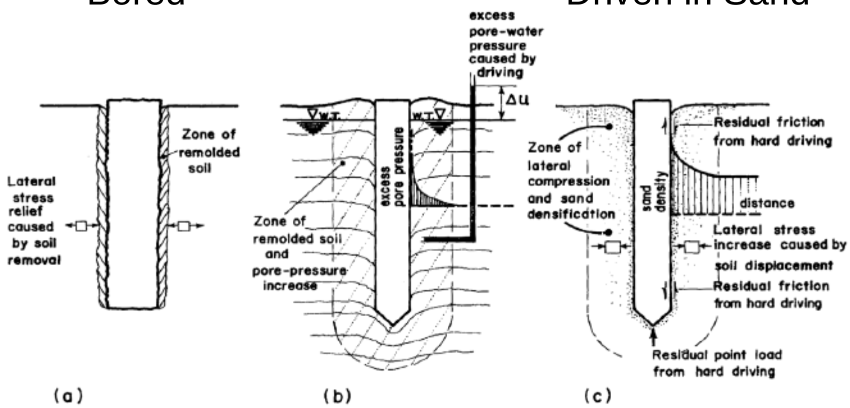
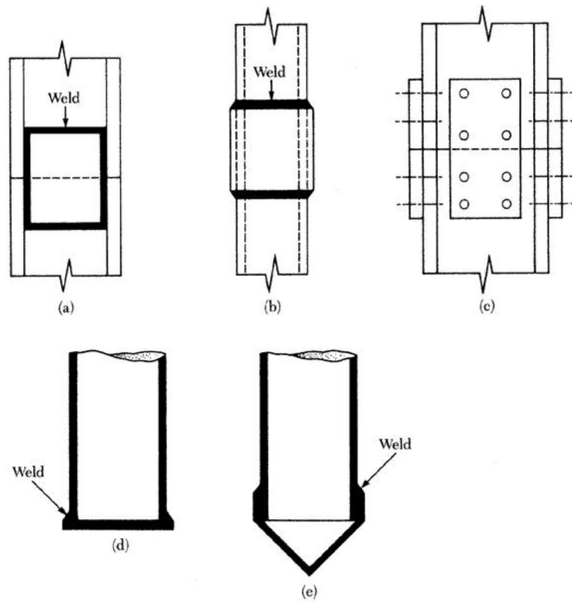


Figure 6. Effects of placement of pile into a soil mass.

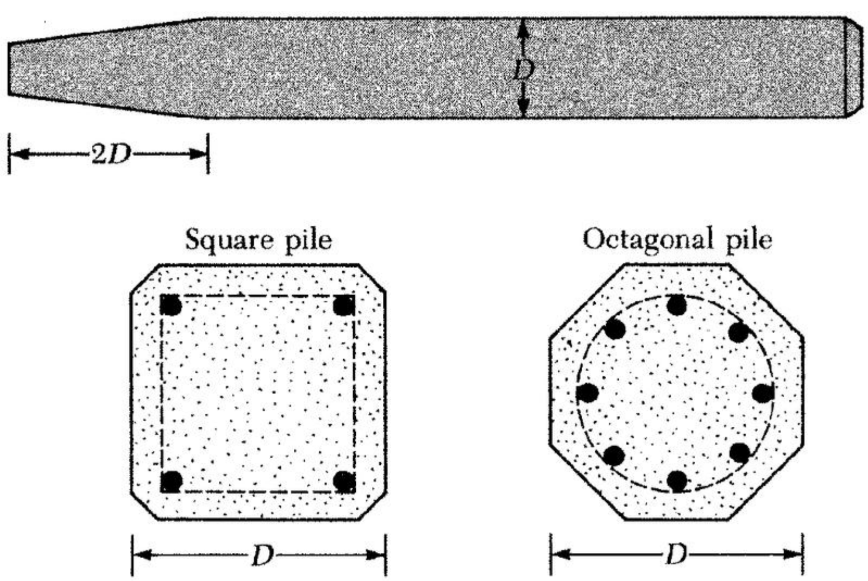
Displacement Piles

Installed by driving or jacking

- TIMBER
  - Marine & temporary structures, domestic buildings
  - Durability concerns
- STEEL TUBES
  - Readily extended
  - Corrosion concerns
  - Usually more expensive
- PRECAST CONCRETE
  - Common lengths 12-15 m
  - Cost & appearance advantages
  - Not suited to hard driving
  - Not easily spliced
- PROPRIETARY TYPES
  - Many use temporary steel casing
  - Casing withdrawn as concrete placed
  - Limitations on length



Steel Piles: (a)splicing of H-pile welding; (b)splicing of pipe pile-welding; (c)splicing of H-pile rivets & bolts (d)flat driving point of pipe pile; (e)conical driving point of pipe pile



Precast piles with ordinary reinforcement

Typical Prestressed Concrete Pile

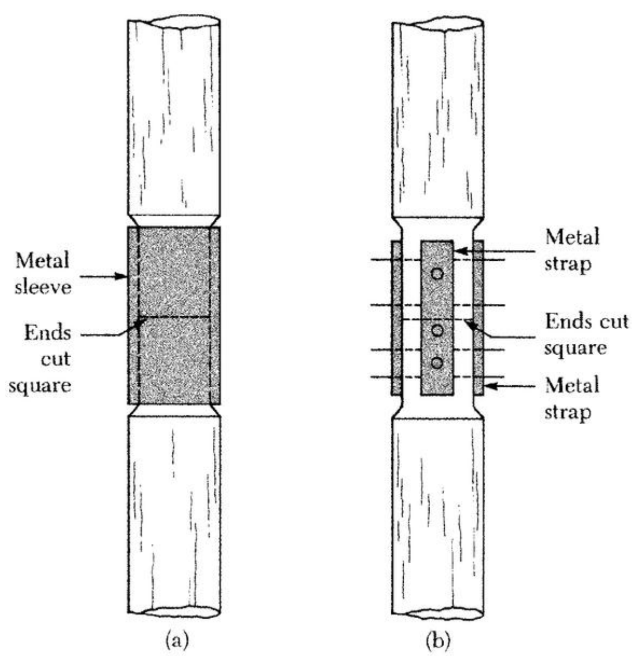
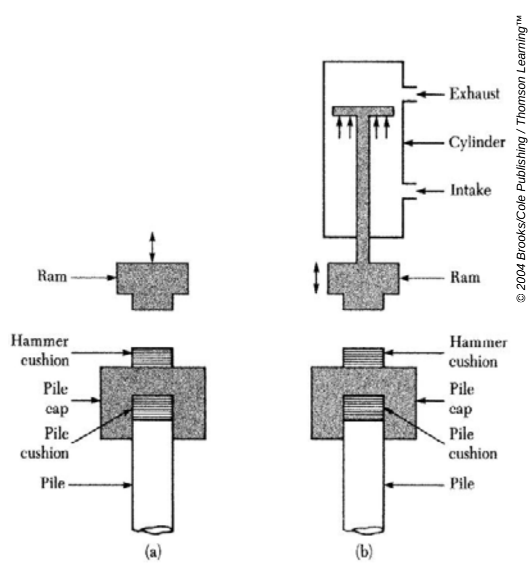


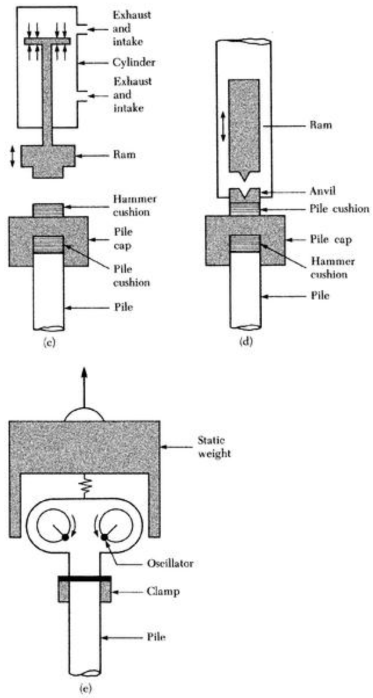
Figure 11.5
Splicing of timber piles:
(a) use of pipe sleeves
(b) use of metal

Installation of Displacement Piles

- Usually installed via pile driving hammer.
- Hammer types:
  - Drop hammer (typically 1-5 t mass)
  - Steam hammer
    - Single acting
    - Double acting
  - Diesel hammer – less used in recent years
  - Hydraulic hammer – ram raised by fluid
  - Vibratory hammer – sheet piles, piles in sand.



Pile-driving equipment:
(a)drop hammer;
(b)single-acting
air or steam



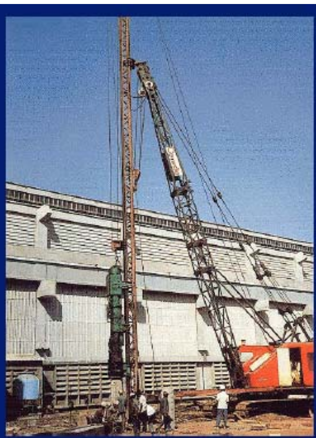
Pile-driving equipment:
(c) double-acting and differential air or steam hammer
(d) diesel hammer
(e) vibratory pile driver

Pile Handling

Driven Piles

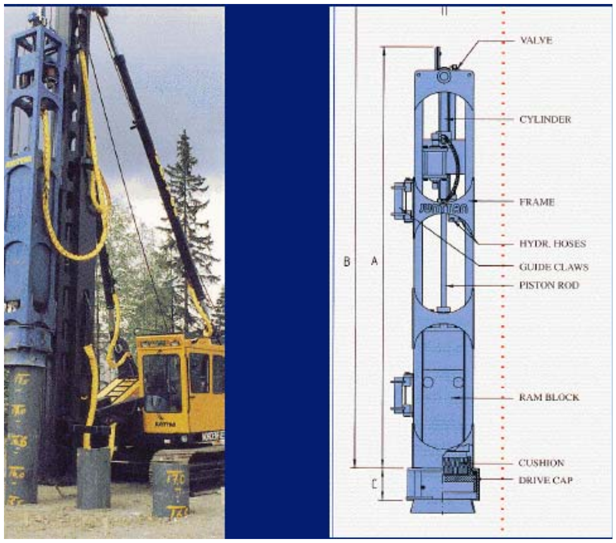
Pile Driving

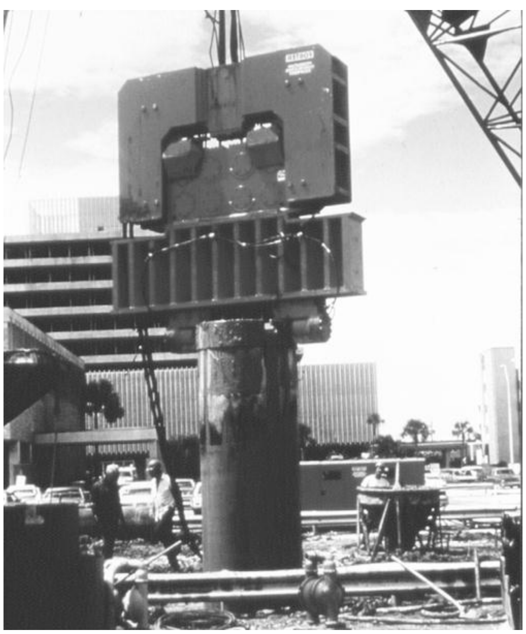
Diesel Hammer



Hydraulic hammer

Hydraulic Hammer





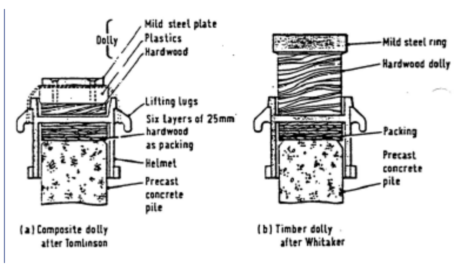
vibratory pile driver

(courtesy of Michael W. O'Neill, University of Houston)

A pile-driving operation in the field

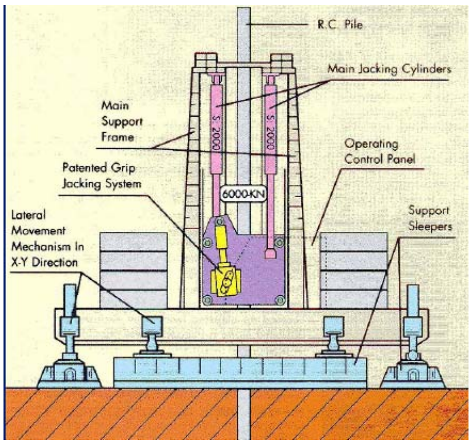
(courtesy of E. C. Shin, University of Incheon, Korea)

Head Assembly



- Helmet:
  Placed over top of pile to help prevent shattering of pile head.
- Driving Cap:
  Protects head of steel piles. Fitted with recess for dolly.
- Dolly:
  Placed on recess in top of helmet. Timber or plastic.
- Packing:
  Placed between helmet & pile top to cushion blows.Hessian, timber sheets, etc.

Pile Jacking



- Pile pushed into ground at a constant rate
- Machine weight 600tons

Pile Jacking

Pile Being Jacked

Concerns with Displacement Piles

- Vibrations during installations
  - Pre site surveys
- Generation of excess porewater pressure
- Soil movements (vertical & lateral)
- Access for driving rigs
- Headroom in confined spaces

Problems From Vertical Soil Displacement

- Uplift causing squeezing necking or cracking
- Uplift resulting in shaft lifting off base
- Uplift resulting in loss of stiffness & bearing capacity
- Ground heave separating pile segments inducing tensile forces in joints, possible cracking of adjacent piles

Problems from Lateral Soil Displacements

- Squeezing of piles
- Inclusion of soil forced into pile
- Shearing of piles or bends in joints
- Collapse of casing prior to concreting
- Movement & damage to adjacent structures

Small Displacement Piles

H-Sections & Rolled Steel Sections

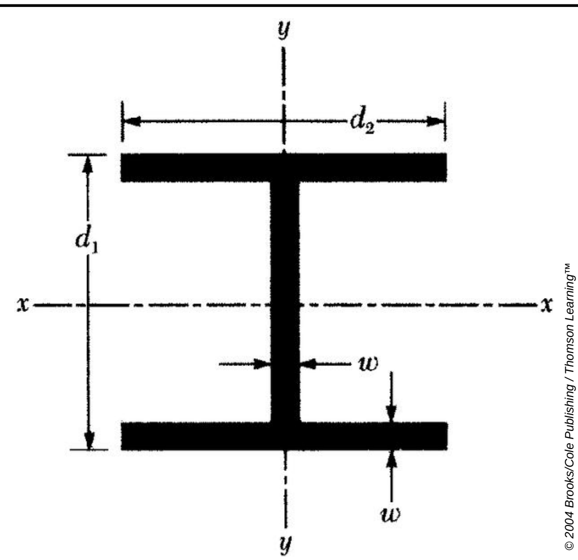
- Useful for punching through hard layers
- BUT, problems with bending about weak axis

Steel Tube Piles

- Lees resistance to water & waves
- Plugs can be removed
- Can fill with concrete
- Better lateral resistance

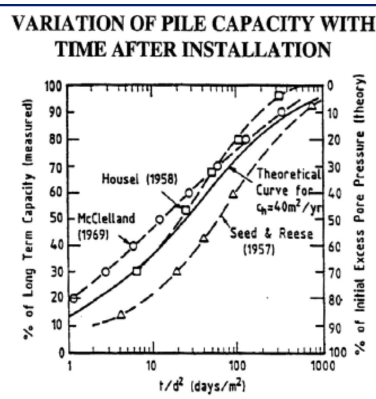
Pre-Drilled Piles

- Usually pre-bored over part depth, then driven
- Useful if have hard layers near surface



Common H-Pile Sections

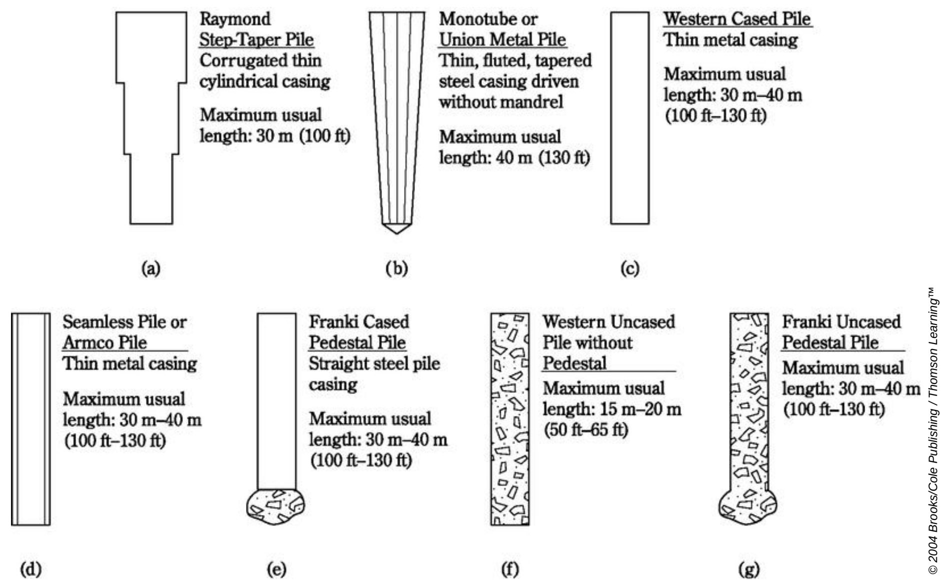
Displacement Piles Time Effect



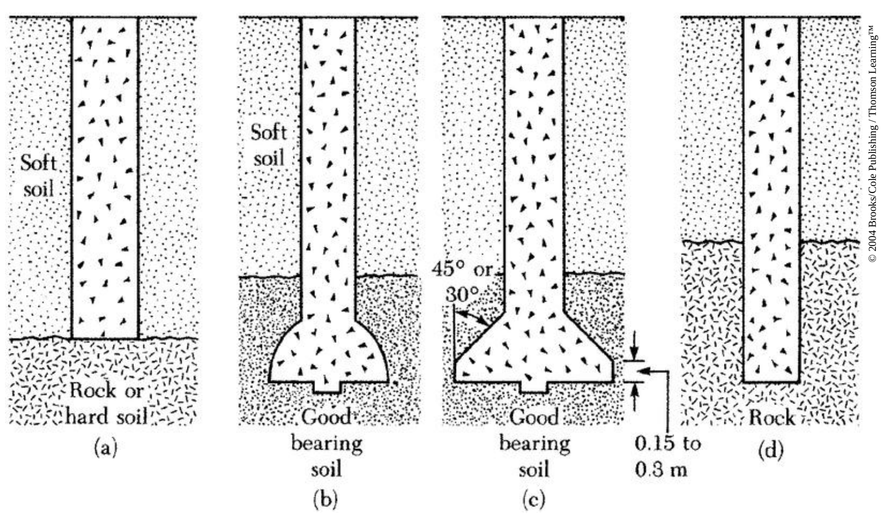
- Dissipation of excess pore pressures developed during driving
- Usually leads to increased load capacity with time – “SET - UP”
- Theoretical solutions and filed data shown
- Can also have set-up effects for driven piles in sand, especially carbonate sands
- May be due to chemical processes at pile-soil interface

Non-Displacement Piles

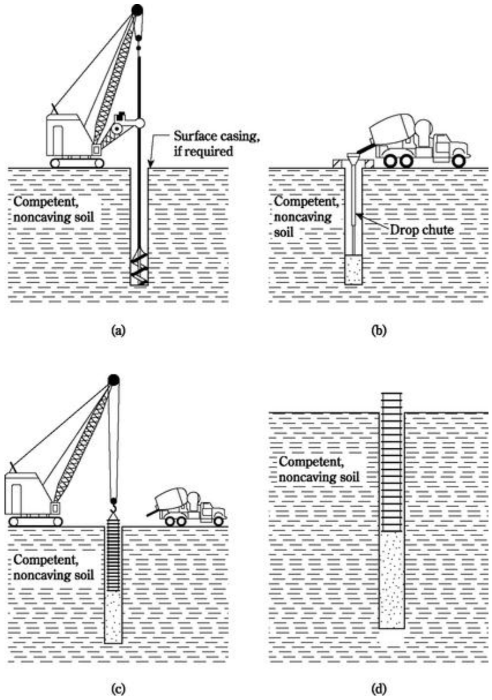
- **INSTALLATION METHODS**
  - Dry
  - Slurry
  - Casing
- **ADVANTAGES**
  - Absence of ground heave
  - No excessive noise or vibration
  - Can install with limited headroom
  - Length & diameter can be easily varied
  - Base can be enlarged
  - Can inspect prior to concreting
  - Can obtain very high capacity
- **PROBLEMS**
  - Loosening of sandy soils
  - Softening of clays
  - Possible waisting or necking of shaft
  - Water inflow can damage shaft
  - Belled bases difficult, especially in sandy soils
  - Need to place concrete as soon as possible after drilling!



Cast-in-place concrete piles

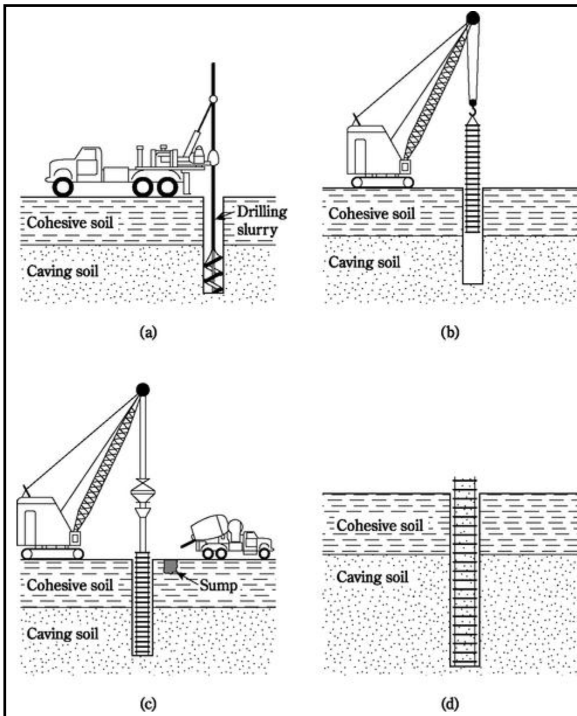


Types of drilled shaft (a) straight shaft;(b) and (c) belled shaft; (d) straight-shaft socketed into rock



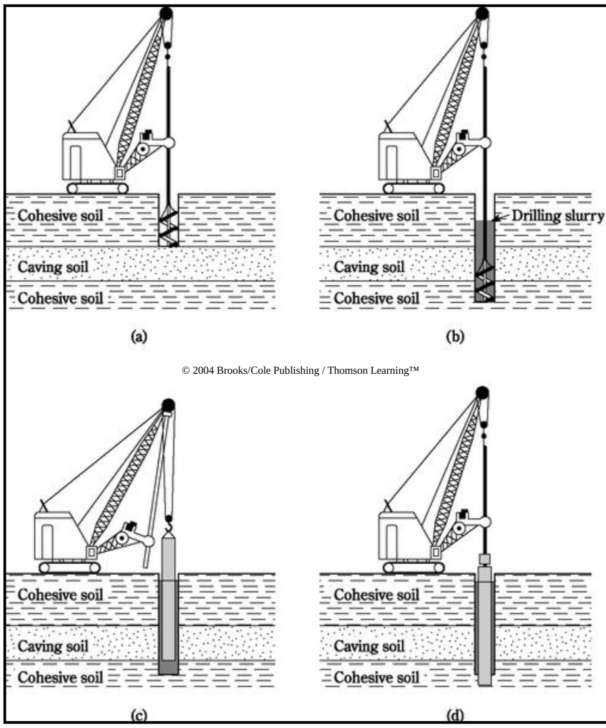
Dry method of construction (a) initiating drilling; (b) starting concrete pour; (c)placing rebar cage; (d) completed shaft

(after O' Neill and Reese, 1999)

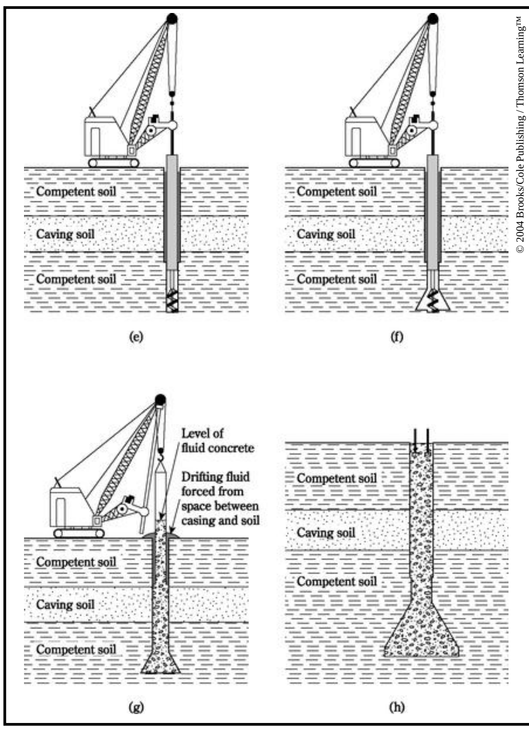


Slurry method of construction a)drilling to full depth with slurry; b)placing rebar cage; c)placing concrete; d)completed shaft

(after O' Neill and Reese, 1999)



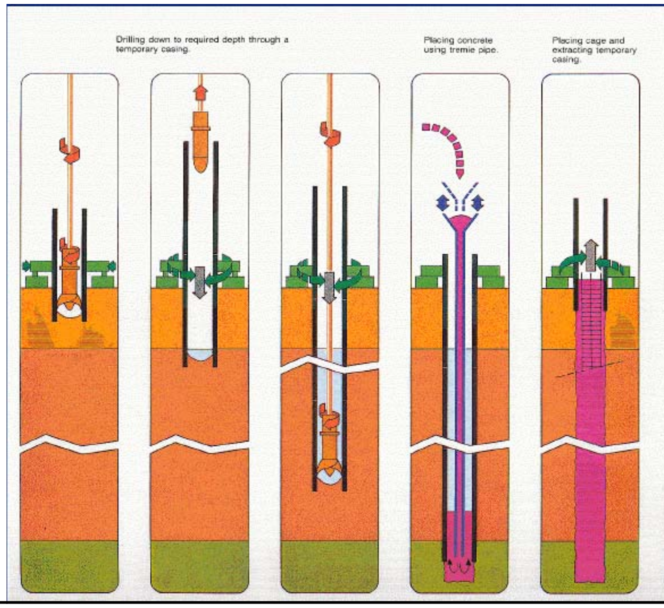
Casing method of construction a) initiating drilling b)drilling with slurry; c)introducing casing; d)casing is sealed & slurry removed from interior of casing



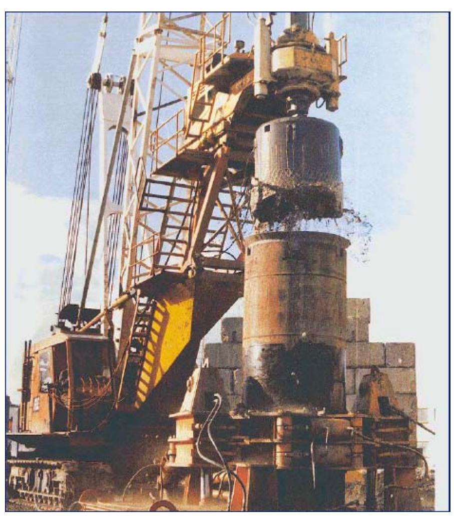
Casing method of construction e)drilling below casing; f)under reaming; g) removing casing; h) completed shaft

(after O' Neill & Reese, 1999)

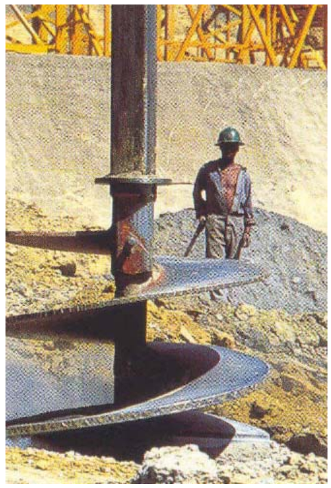
Bored Piles

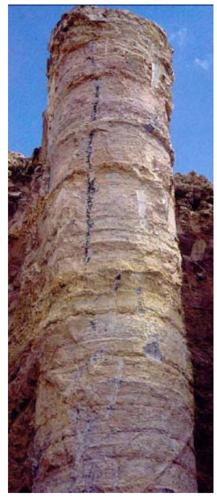


Bored Piles

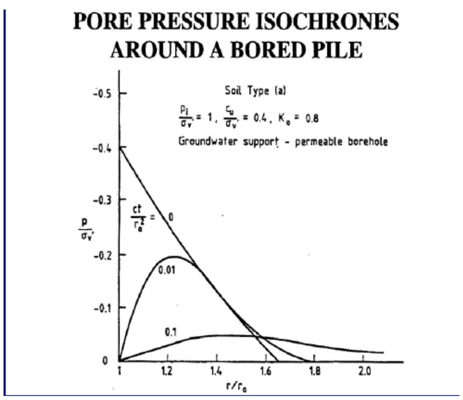


Bored Piles





Bored Piles Time Effect

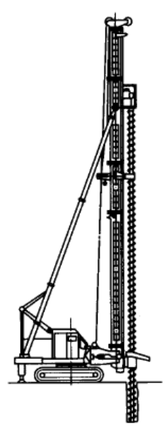


- Reduction is suction after drilling
- Consequent softening & possible caving of hole
- Solutions for pore pressures vs time shown
- Typically, for a bored pile 0.8 m diameter, with soil $c_v = 10^{-5}$ m/s, T=0.1 corresponds to less than ½ hour !

Bored Pile Precautions

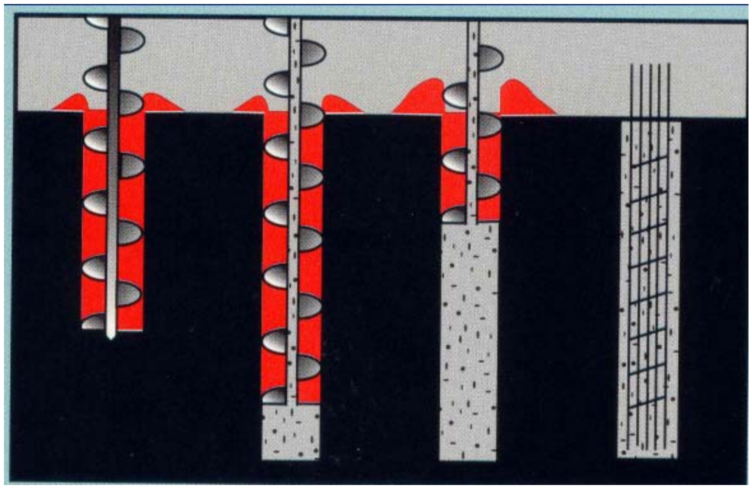
- Pile should be supported by casing through soft or loose soils to prevent collapse
- Casing provided to seal off water-bearing layers
- Strict control of density of drilling fluid, if used
- Compare soil & rock cuttings from pile & descriptions form site investigation
- Shear strength tests from bottom of selected piles to check against design assumptions
- Plumb deep holes immediately after concreting; compare plumbed depth with that at end of drilling
- Proper measures for base cleaning – video or visual inspection where possible
- Safety procedures followed strictly
- **Time interval between end of boring & concreting kept as short as possible, no longer than 6 hours.**

Continuous Flight Augers

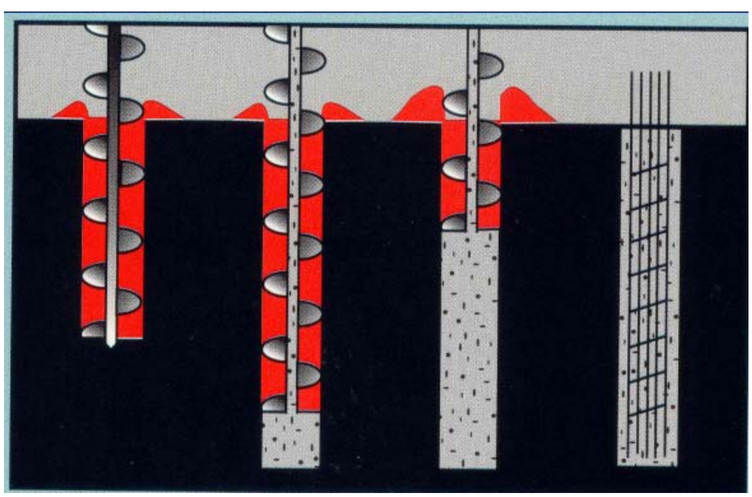


- Flight auger has hollow stem
- Borehole walls supported by soil rising within flights
- Concrete (fluid grout) injected down hollow stem
- Reinforcing cage installed after auger removed
- Strict construction control ESSENTIAL, especially if require end bearing
- Checks via recording of volume of concrete and torque on drill stem
- Size Limits: Diameter 1.5m; Length 35m

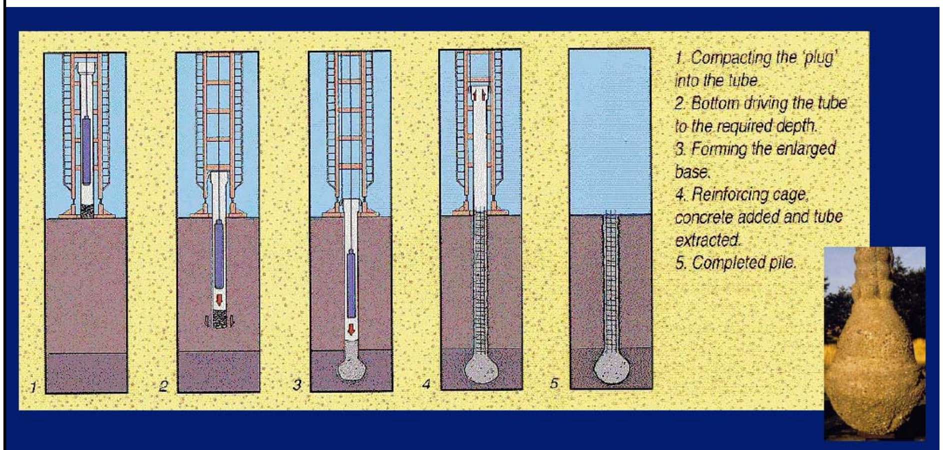
Continuous Flight Augers
Grout Injected



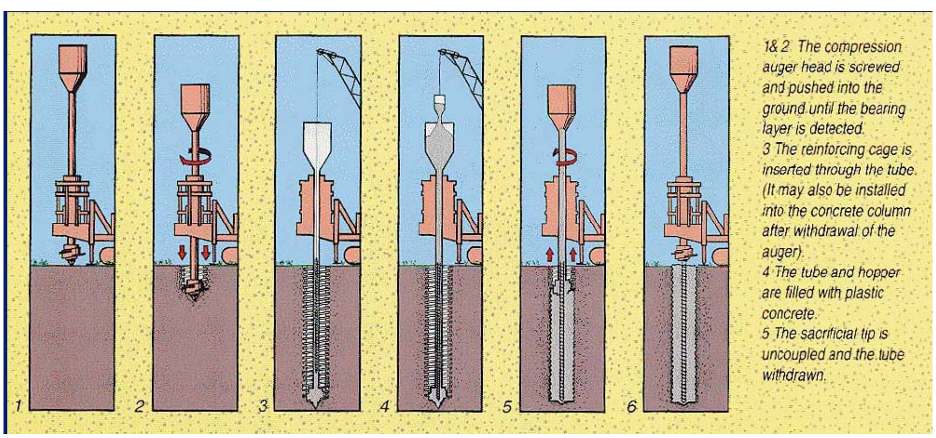
Continuous Flight Augers
Grout Injected



Franki Pile

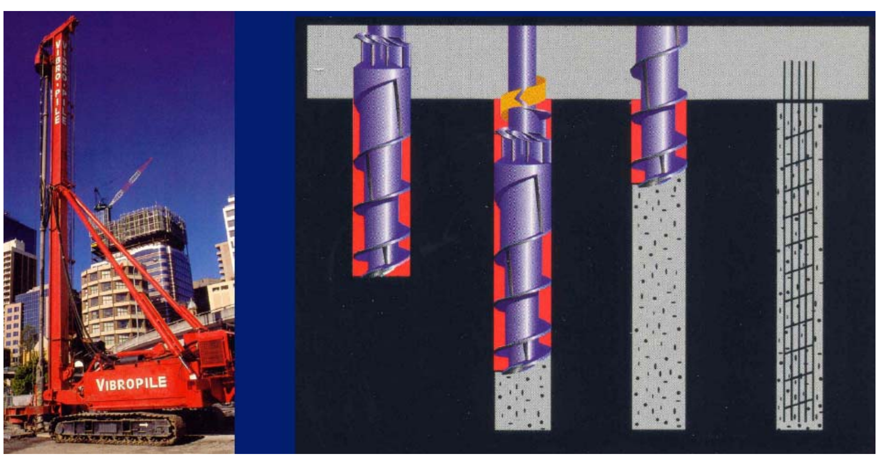


Atlas Pile



Atlas Pile

Omega Pile



Pile Design Requirements

- **Ultimate limit state**
  - Adequate capacity (geotechnical & structural) to resist ultimate load combinations
- **Serviceability limit state**
  - Deflections and differential at normal "working" loads are within tolerable limits
- **Durability**
  - Piles must remain durable during design life, or else be designed for acceptable deterioration

Pile Design Considerations

- Selection of pile type and installation method
- Size & number of piles for adequate factor of safety
- Settlement & differential settlement checks
- Effects of lateral loading
- Effect of ground movements (if any)
- Evaluation of pile performance – load testing

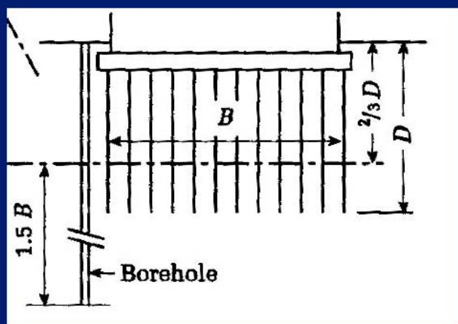
Section of Pile Type

Depends on:

- Location & type of structure
- Ground conditions
- Access for piling equipment
- Durability requirements
- Effects of installation on adjacent piles, structures, people
- Relative costs

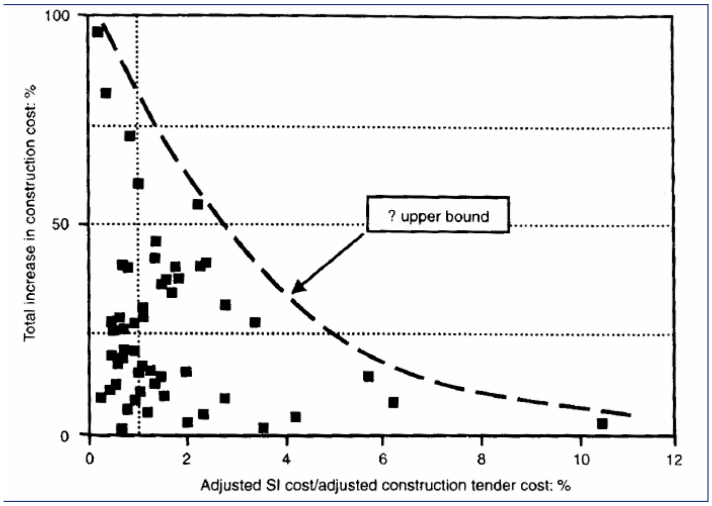
Site Investigation

- Is as important for pile foundations as for shallow foundations.
- Need to extend exploration to depth of influence of pile or pile group.
- Need to prove rock or founding material – usually drill min. 3m into rock.
- Beware of compressible layers below the pile tips.



Tomlinson's suggestion for depth of investigation

How Much SI?



Design Approaches

OVERALL SAFETY FACTOR

$P_w = P_u / FS$

PARTIAL SAFETY FACTORS (European)

- Factor up loads and use factored-down soil parameters to compute design resistance

LOAD & RESISTANCE FACTORED DESIGN (LRFD)

- Resistance computed using factored down ultimate shaft & base capacities = R_d
- Load factored up by load factors $= S_d$
- $\mathbf{R_d > S_d}$

PROBABILISTIC APPROACH

- P(failure) < Allowable value (e.g. 10^{-4})

Analysis & Design Methods

- ***Category 1***
  - Empirical
- ***Category 2***
  - Soundly-based, simplified theory and/or charts
- ***Category 3***
  - 3A - Site-specific theory - simple soil
  - 3B - Site-specific - simple nonlinear soil
  - 3C - Site-specific - proper soil model

Analysis & Design Methods

Table 1. Categories of analysis/design procedures

Category	Subdivision	Characteristics	Method of parameter determination
1	—	Empirical—not based on soil mechanics principles	Simple in situ or laboratory tests, with correlations
2	2A	Based on simplified theory or charts—uses soil mechanics principles—amenable to hand calculation. Theory is linear elastic (deformation) or rigid plastic (stability)	Routine relevant in situ tests—may require some correlations
	2B	As for 2A, but theory is non-linear (deformation) or elasto-plastic (stability)	
3	3A	Based on theory using site-specific analysis, uses soil mechanics principles. Theory is linear elastic (deformation) or rigid plastic (stability)	Careful laboratory and/or in situ tests which follow the appropriate stress paths
	3B	As for 3A, but non-linearity is allowed for in a relatively simple manner	
	3C	As for 3A, but non-linearity is allowed for by way of proper constitutive models of soil behaviour	

How Good Are Predictions?