FOUNDATIONS FOR WIND TURBINES

ENGR 340 – Fall 2011

Jeramy C. Ashlock
Assistant Professor, CCEE

Vern Schaefer
Professor, CCEE

OUTLINE

Topics	Lecture #
Design requirements, Foundation types	1
Overview of geotechnical engineering • Soil mechanics • Site investigations • In-situ tests • Laboratory tests	1 & 2
Foundations for wind turbines, Design example	2

OBJECTIVES

1. Introduce students to foundation design and provide brief background on geotechnical engineering

2. Provide students with the ability to select the most suitable types of wind turbine foundations for a given site

3. Discuss a typical gravity foundation design procedure for an onshore wind turbine

DEFINITIONS

- Foundation

  Part of an engineering system which transmits loads to underlying soil or rock. Foundations are structural elements under buildings, bridges, towers, wharfs, piers, industrial equipment, etc.

- Foundation Engineering

  The art of selecting, designing, and constructing the elements that transfer structural loads such as those from self-weight, wind, traffic, wave, or earthquake loads to the underlying soil or rock.

REQUIRED KNOWLEDGE FOR FOUNDATION DESIGN

1. The loads that will be transmitted by the superstructure to the foundation system (vertical, horizontal, moment, torsion)
2. Requirements of the local building code
3. The strength and stress-related deformability of soils that will support the foundation system
4. Geological conditions of the soil under consideration

REQUIRED KNOWLEDGE FOR FOUNDATION DESIGN

"Since the design geometry and location of the substructure element often have an effect on how the soil responds, the foundation engineer must be reasonably versed in structural design."

J. E. Bowles

Foundation Analysis and Design, 3rd ed.

DESIGN CRITERIA

1. Bearing Capacity— the strength of the soil to withstand loads and resist failure
2. Settlement—the deformation of the soil under service loads (a serviceability limit state)
3. Constructability—is it possible to build the foundation system as designed?
4. Cost—can the foundation system be constructed within a reasonable budget, or are more economical alternatives feasible?

DESIGN CRITERIA

ASCE (1976). *Subsurface Investigation For Design and Construction of Foundations of Buildings*, Manuals and Reports on Engineering Practice - No. 56, American Society of Civil Engineers, New York, NY, 61 pp.

Foundation engineering for building is directed towards three objectives:

1. Loadings imposed by the foundation elements sufficiently less than the ultimate capacity of the soil to assure foundation safety
2. Limitation of total and differential settlements within acceptable limits for the structure
3. Control of the effects of the structure and its necessary construction operations to limit displacements of ground at and under adjoining buildings, streets, and facilities to tolerable amounts both during and after construction.

TOTAL VS. DIFFERENTIAL SETTLEMENTS

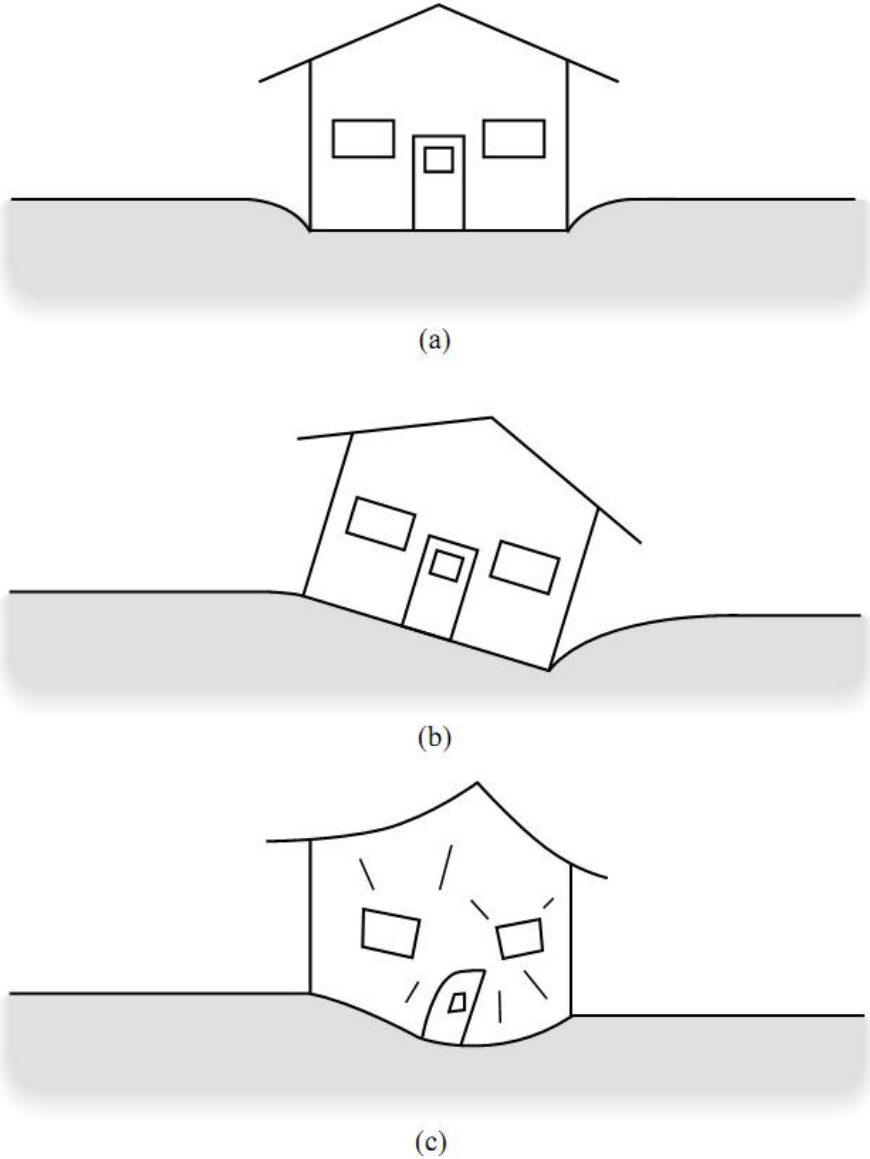


Figure 2.3 Modes of settlement; (a) uniform; (b) tilting with no distortion; (c) distortion.

MINIMUM STEPS FOR DESIGNING A FOUNDATION (AFTER BOWLES)

1. Locate the site and the position of the load. A rough estimate of the foundation loads is usually provided by the client or made in-house. Depending on the site or load system complexity, a literature survey may be started to see how others have approached similar problems.

2. Physically inspect the site for any geological, or other, evidence of possible problems. Supplement this with any previously obtained soil data.

MINIMUM STEPS FOR DESIGNING A FOUNDATION (AFTER BOWLES)

3. Establish the field exploration program and on the basis of discovery set up the necessary supplemental field testing and the laboratory test program.

4. Determine the necessary soil design parameters based on integration of the test data, scientific principles, and engineering judgment. Simple or complex computer analyses may be involved. For complex problems, compare the recommended data with published literature or engage another geotechnical consultant to give an outside perspective to the results.

MINIMUM STEPS FOR DESIGNING A FOUNDATION (AFTER BOWLES)

5. Design the foundation using the soil parameters from Step 4. The foundation should be economical and be able to be built by the available construction personnel (and equipment). Take into account practical construction tolerances and local construction practices. Interact closely with all concerned (client, engineers, architect, contractor) so that the substructure system is not excessively overdesigned and risk is kept within acceptable levels.

FOUNDATION TYPES

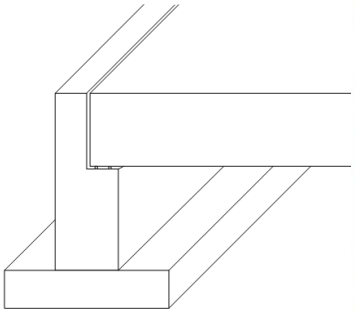


Figure 2-3: Spread Footing with Cantilever Stemwall at Bridge Abutment

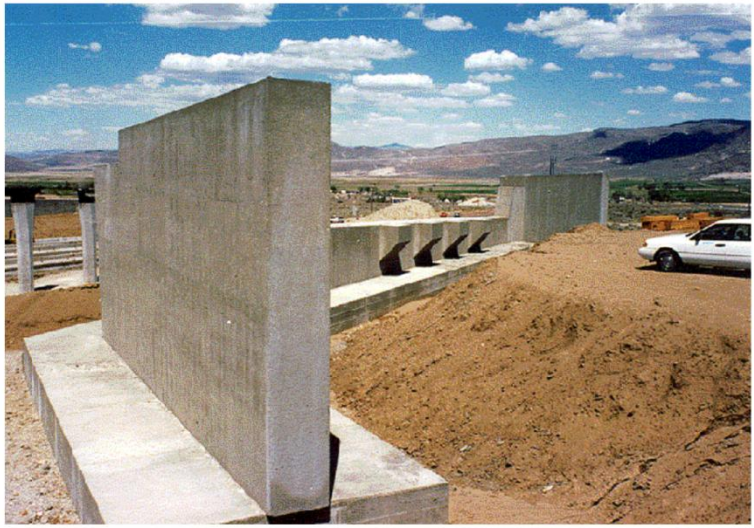


Figure 2-14: Footing at South Abutment, I-580, Nevada

5 ft diameter, 75 ft long drilled shaft, Broadway viaduct, Council Bluffs

SHALLOW VS. DEEP FOUNDATIONS

Shallow foundations (gravity-based)

- Generally have an embedment ratio of $D_f \leq B$
  (B= smallest width)

Deep foundations

- used when greater <u>load capacities</u> (heavier structures) or when <u>lower settlements</u> are required
- Transmit loads to deeper layers of soil by:
  1. <u>friction</u>
  2. <u>end bearing</u> on stiffer layers or bedrock
  3. a combination of friction & end-bearing

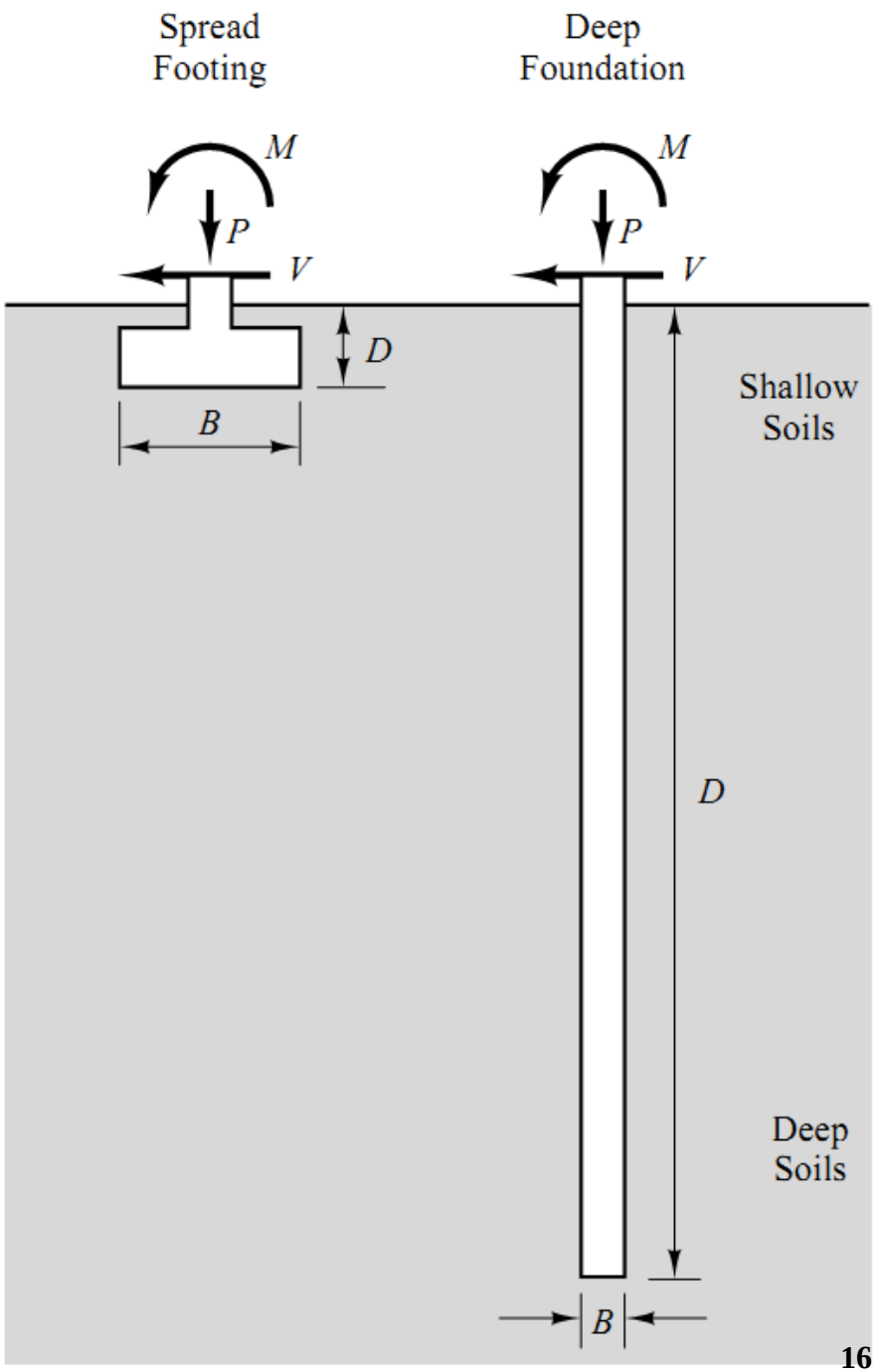
FOUNDATION TYPES

- Shallow
  - Spread footings: circular, square, rectangular, or continuous (a.k.a. strip or wall) footings
  - Mats a.k.a. rafts
- Deep
  - Driven piles, drilled shafts/caissons, augercast piles
- Intermediate
  - Rammed aggregate piers, stone columns, impact piers

SHALLOW VS. DEEP FOUNDATIONS

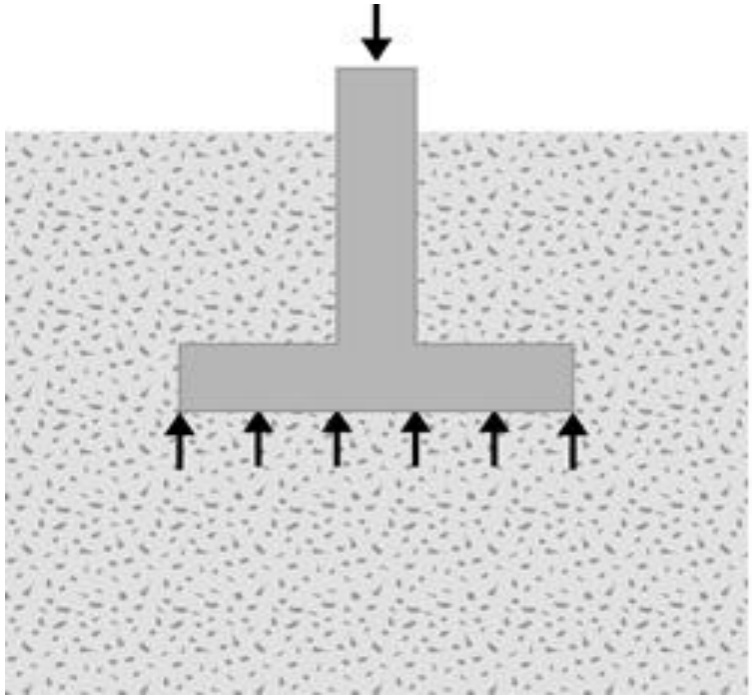
- Deep foundations may be required if shallow soils can not provide enough strength

- Depending on soil properties, intermediate foundations may also be an economical alternative

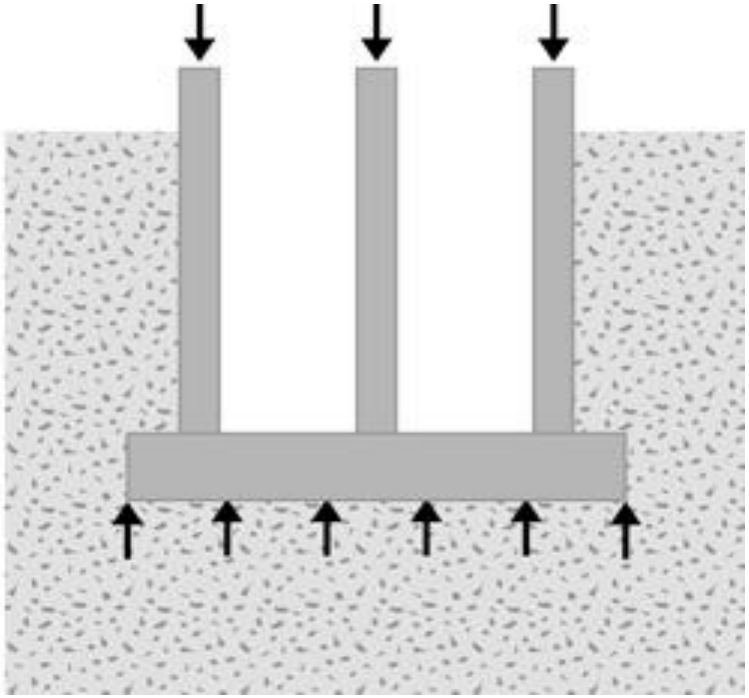


SHALLOW FOUNDATIONS

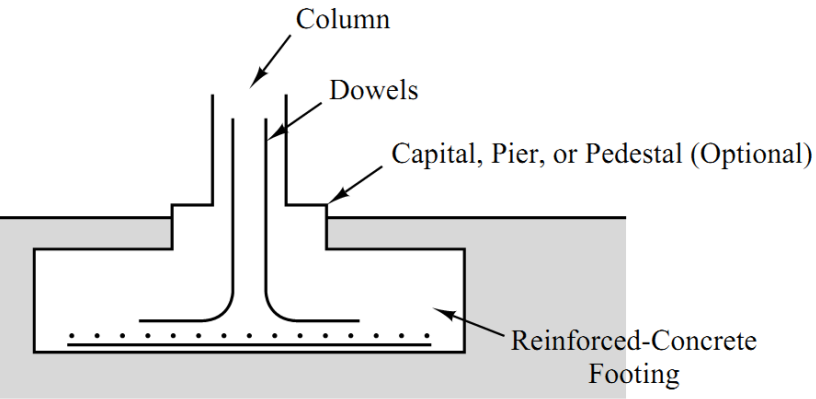
Spread footing



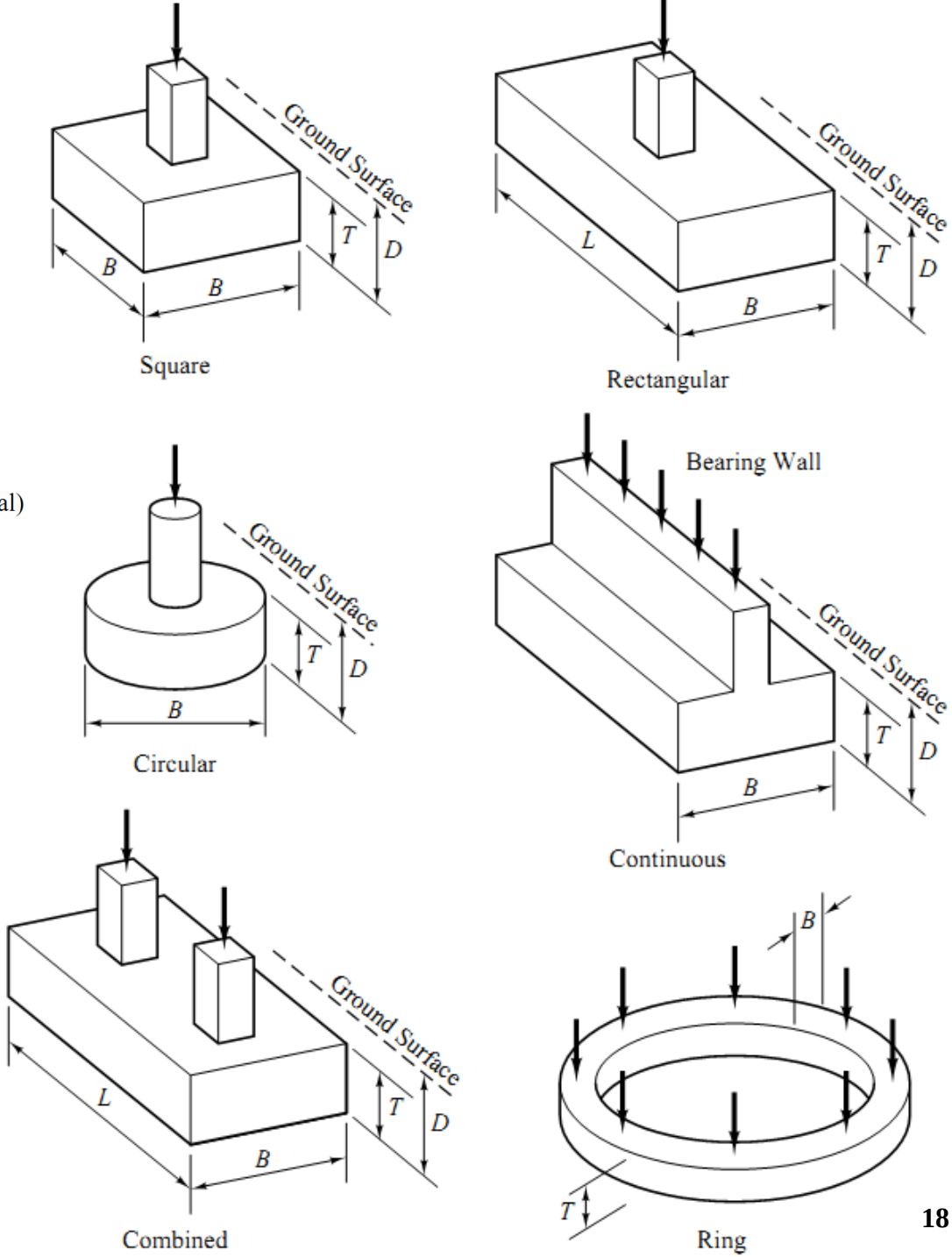
Mat foundation



SPREAD FOOTINGS



Steel reinforced concrete

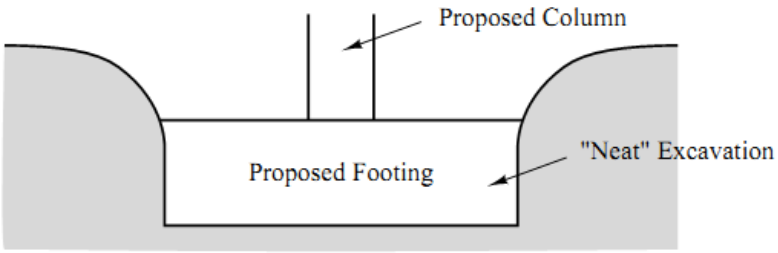


SPREAD FOOTING FORMING METHODS

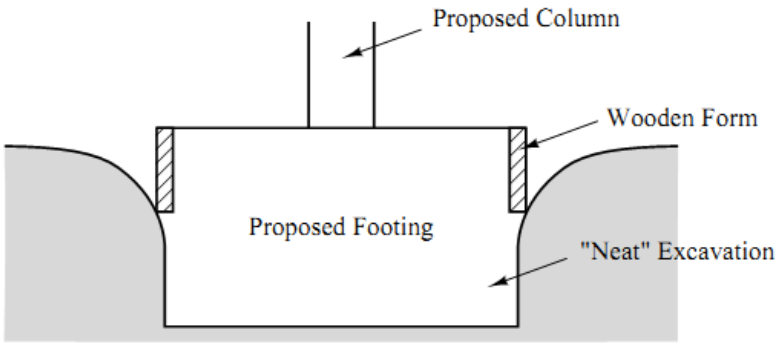
(a)“Neat” excavation

(b) Neat excavation with wooden formwork at top

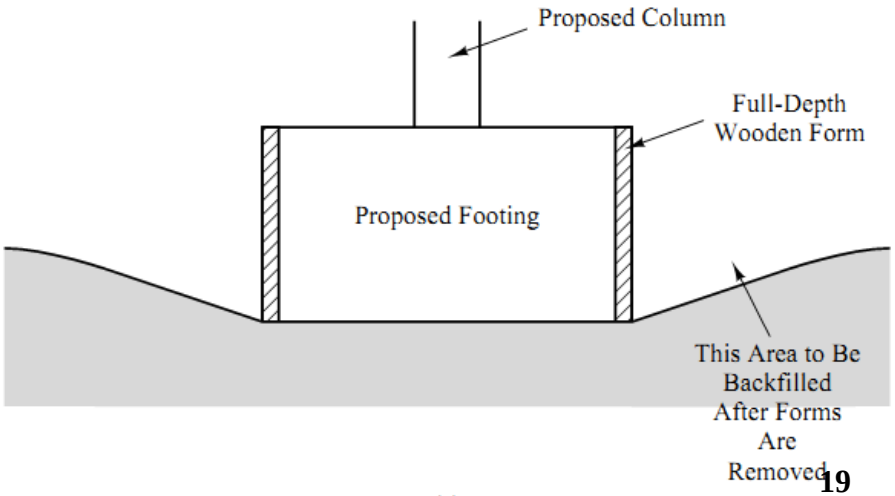
(c) Full depth wooden forms, backfill placed after forms are removed



(a)



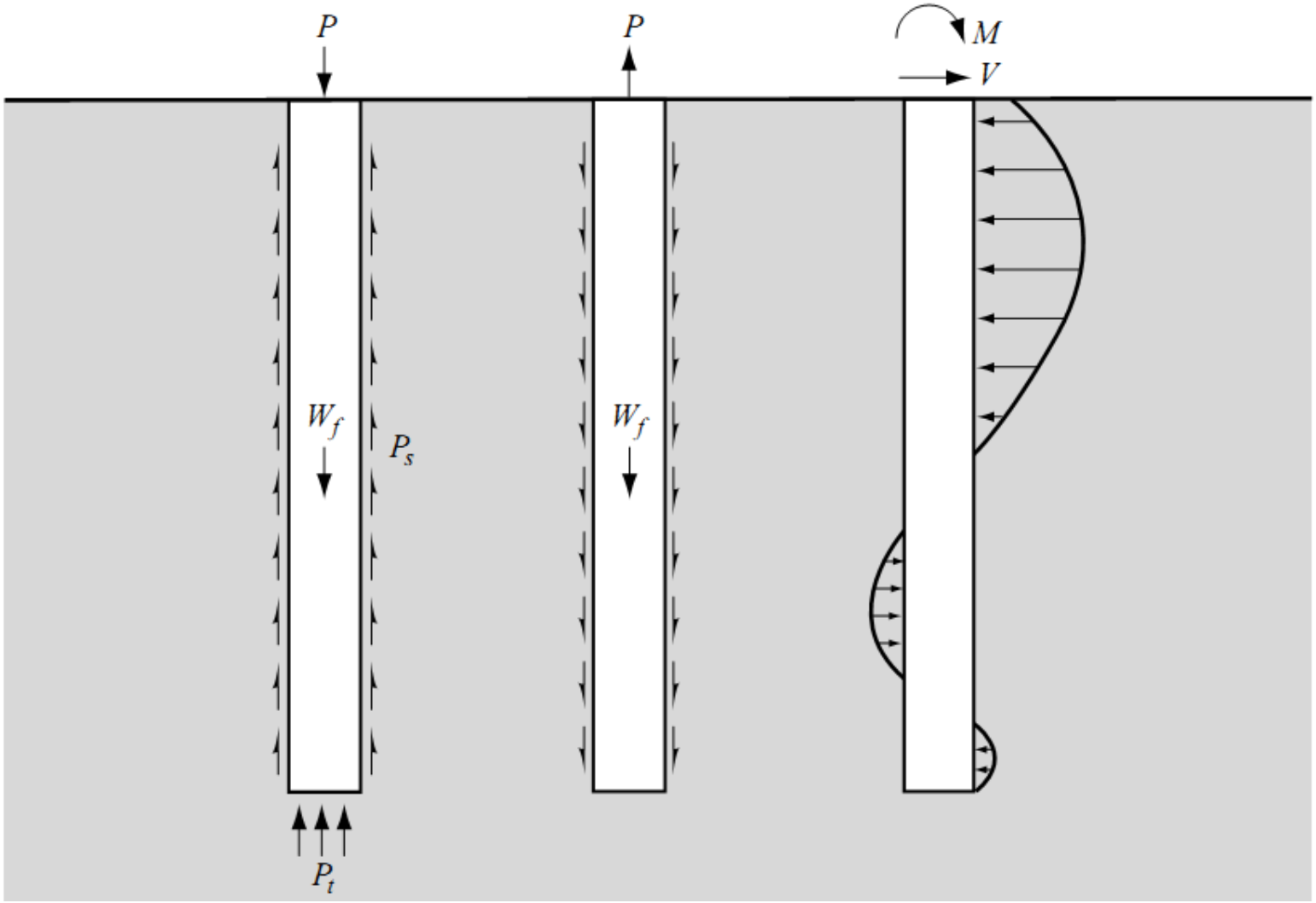
(b)



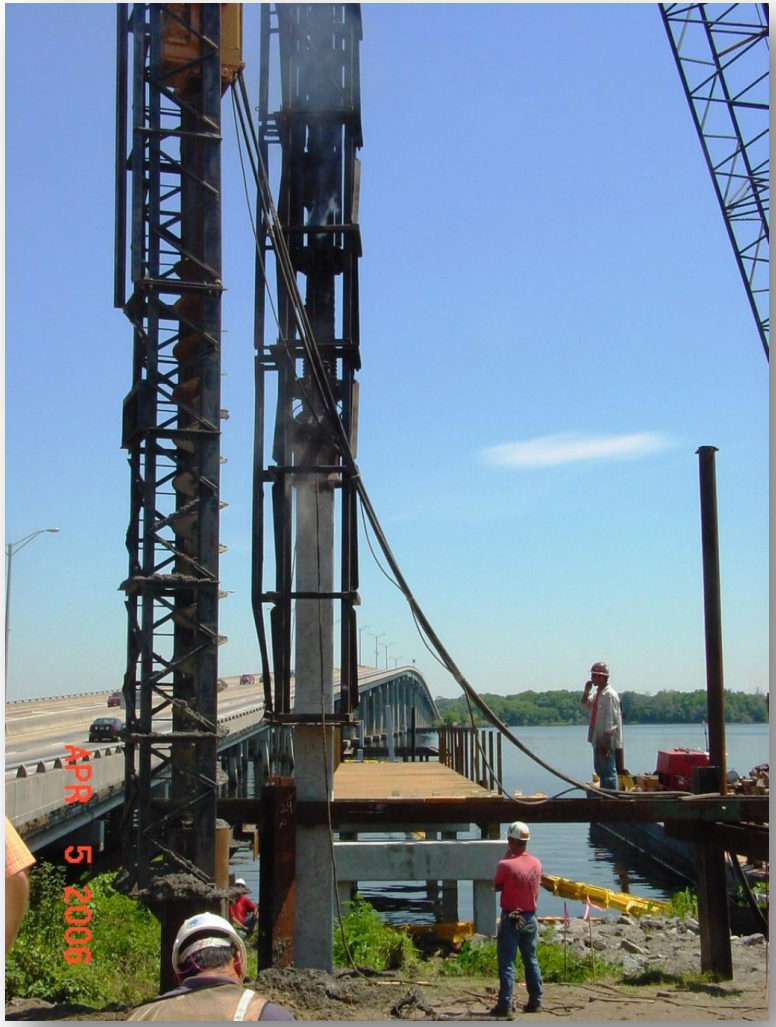
(c)

DEEP FOUNDATIONS: LOAD TRANSFER MECHANISMS

Compressive Tensile/uplift Moment and lateral loads



DRIVEN PILES



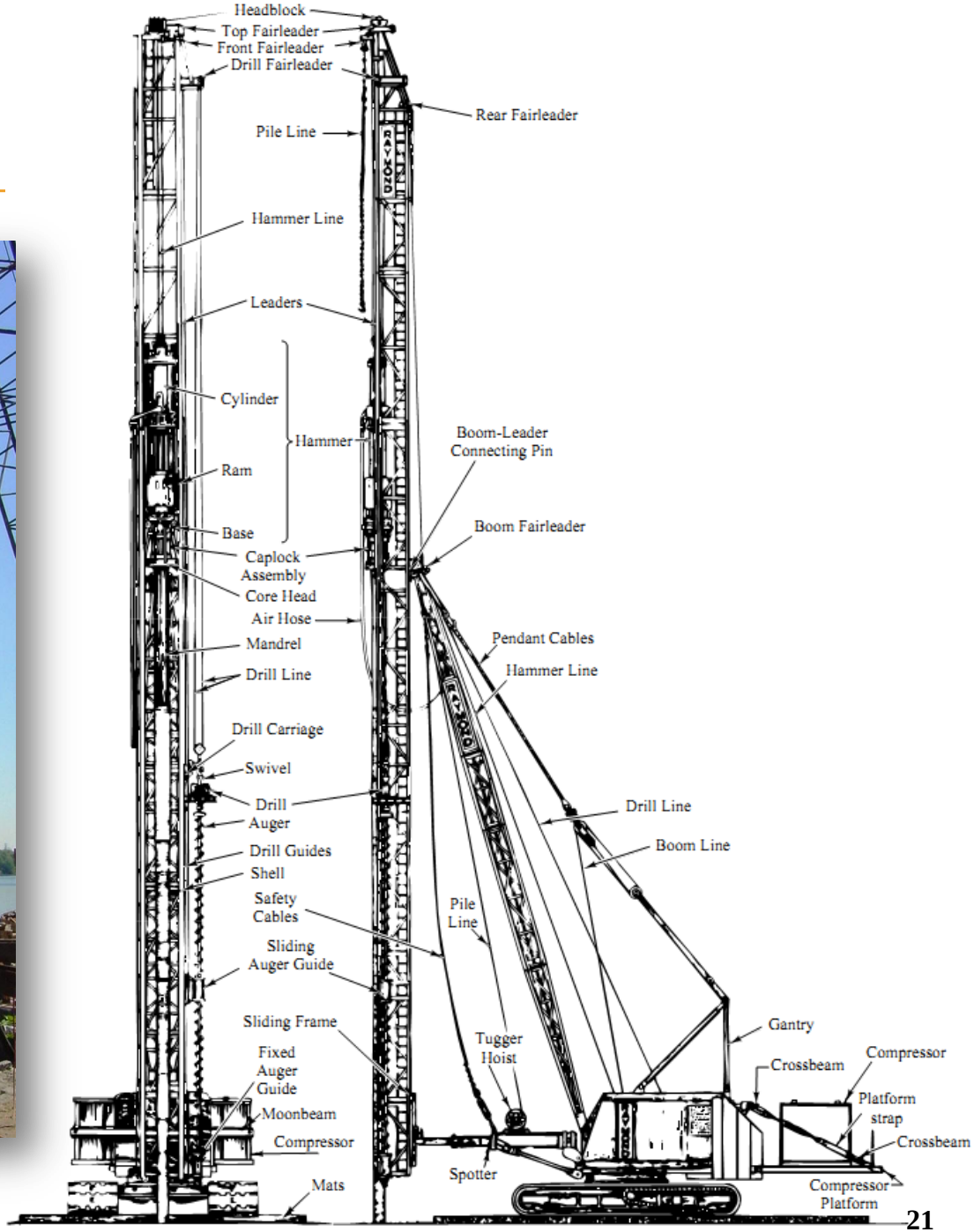


Figure 11.17 A modern pile-driving rig (Raymond International Builders).

DRIVEN PILES

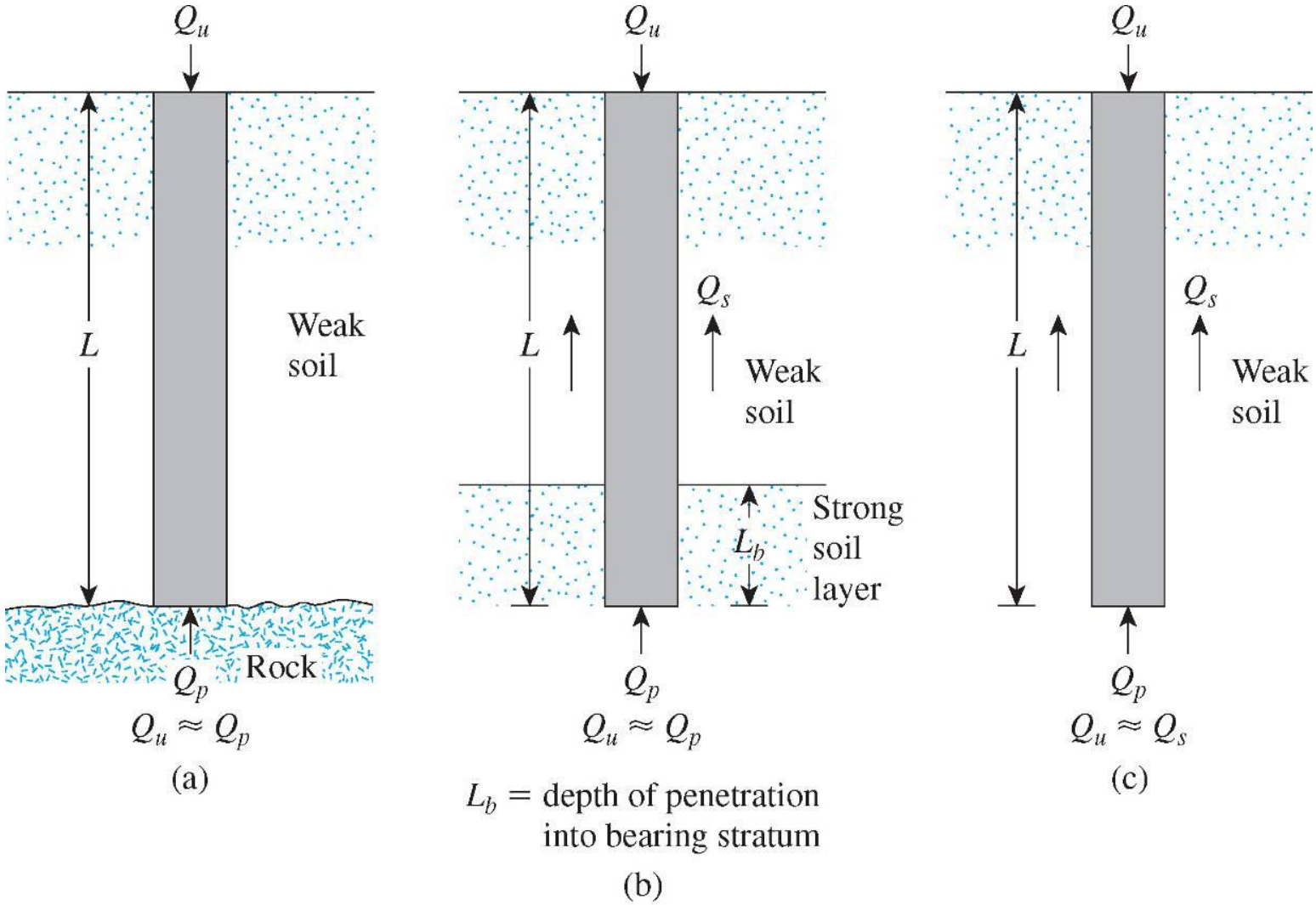
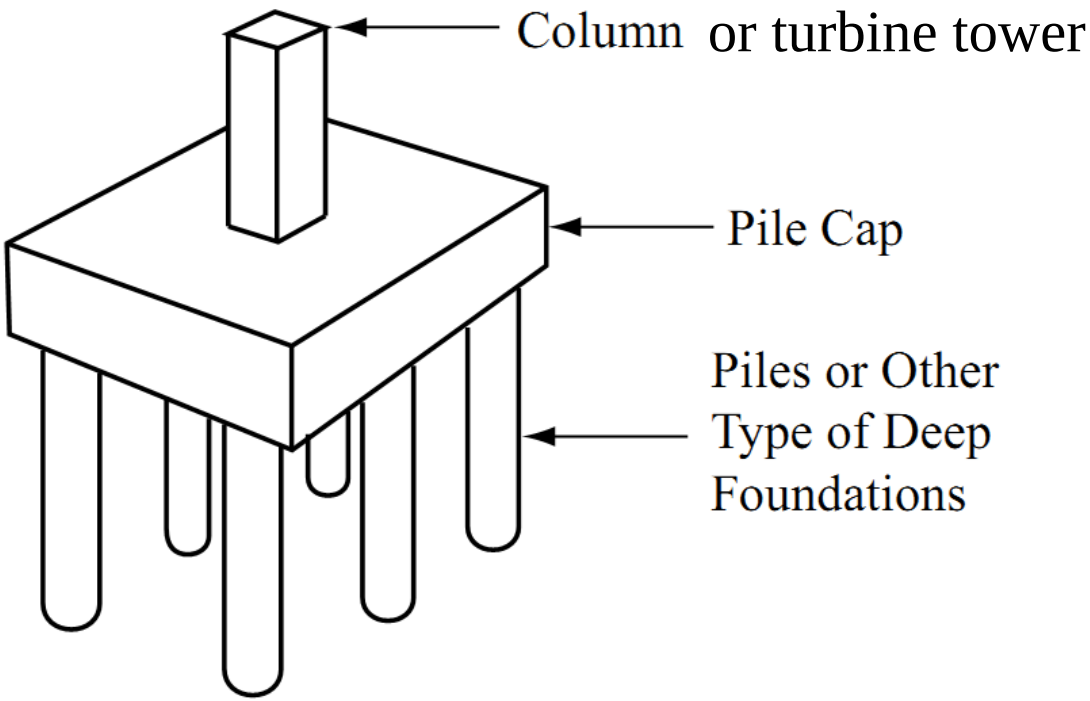


Figure 11.6 (a) and (b) Point bearing piles; (c) friction piles

PILE CAPS: STRUCTURAL CONNECTION



AUGERCAST PILES

a.k.a. *augered cast-in-place piles*

In Europe: known as *continuous flight auger (CFA) piles*

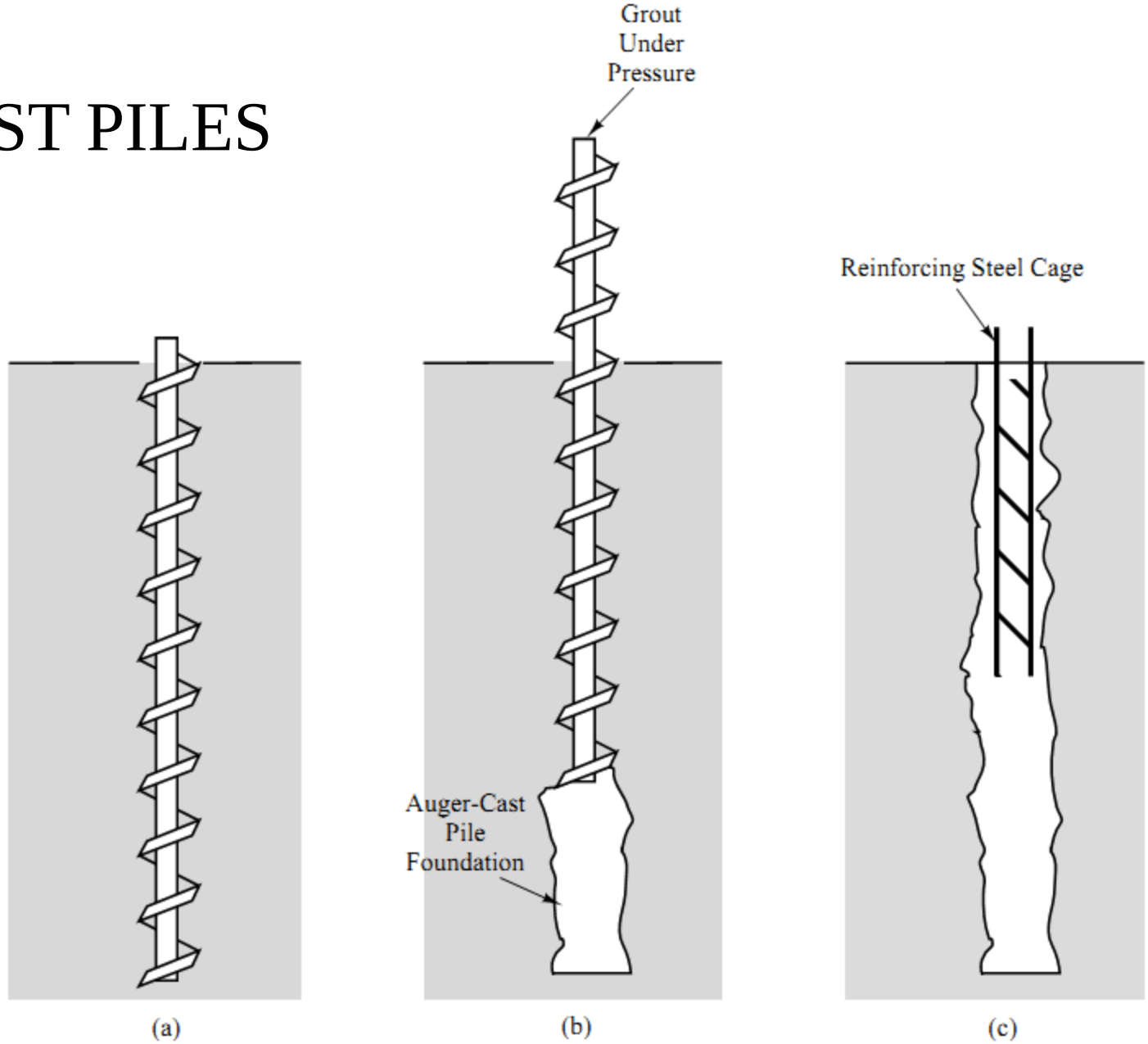
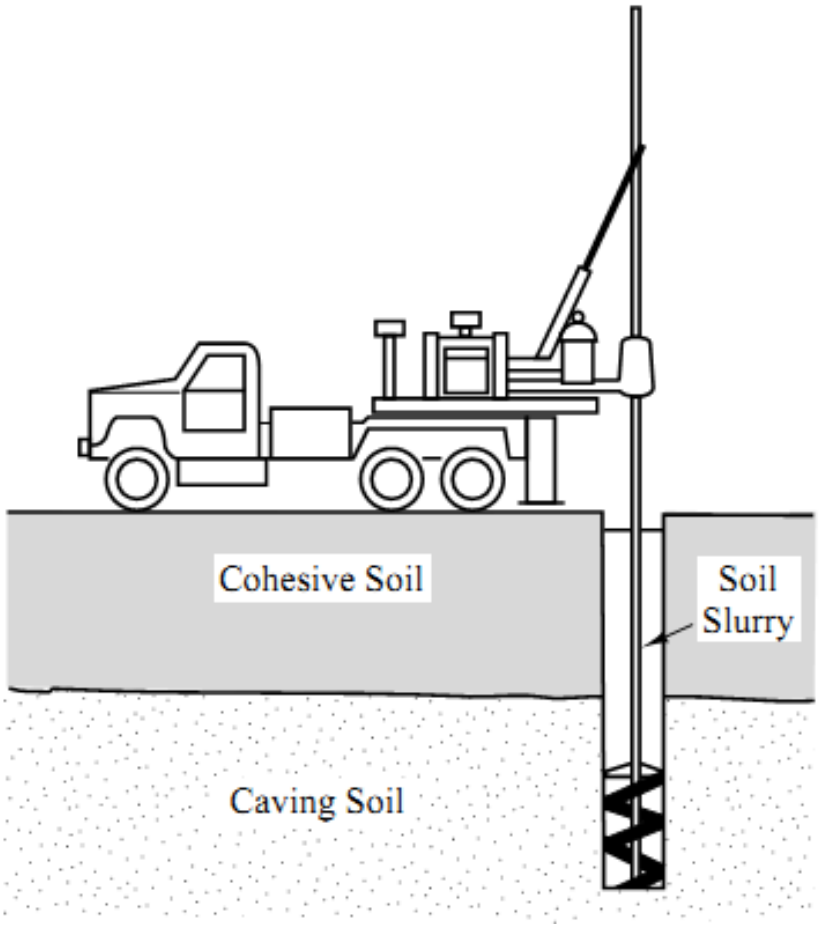
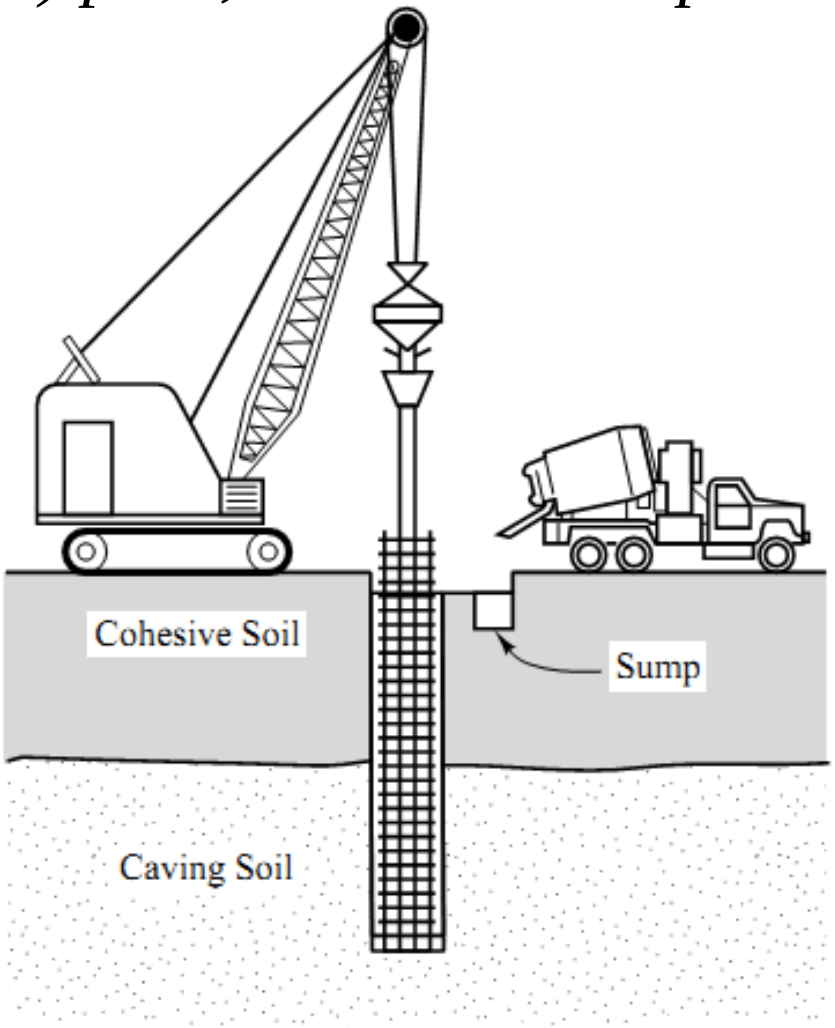


Figure 11.47 Construction of an auger-cast pile: (a) Drill to the required depth using a hollow-stem auger; (b) Withdraw the auger while injecting cement grout; (c) Install steel rebars (optional).

DRILLED SHAFTS

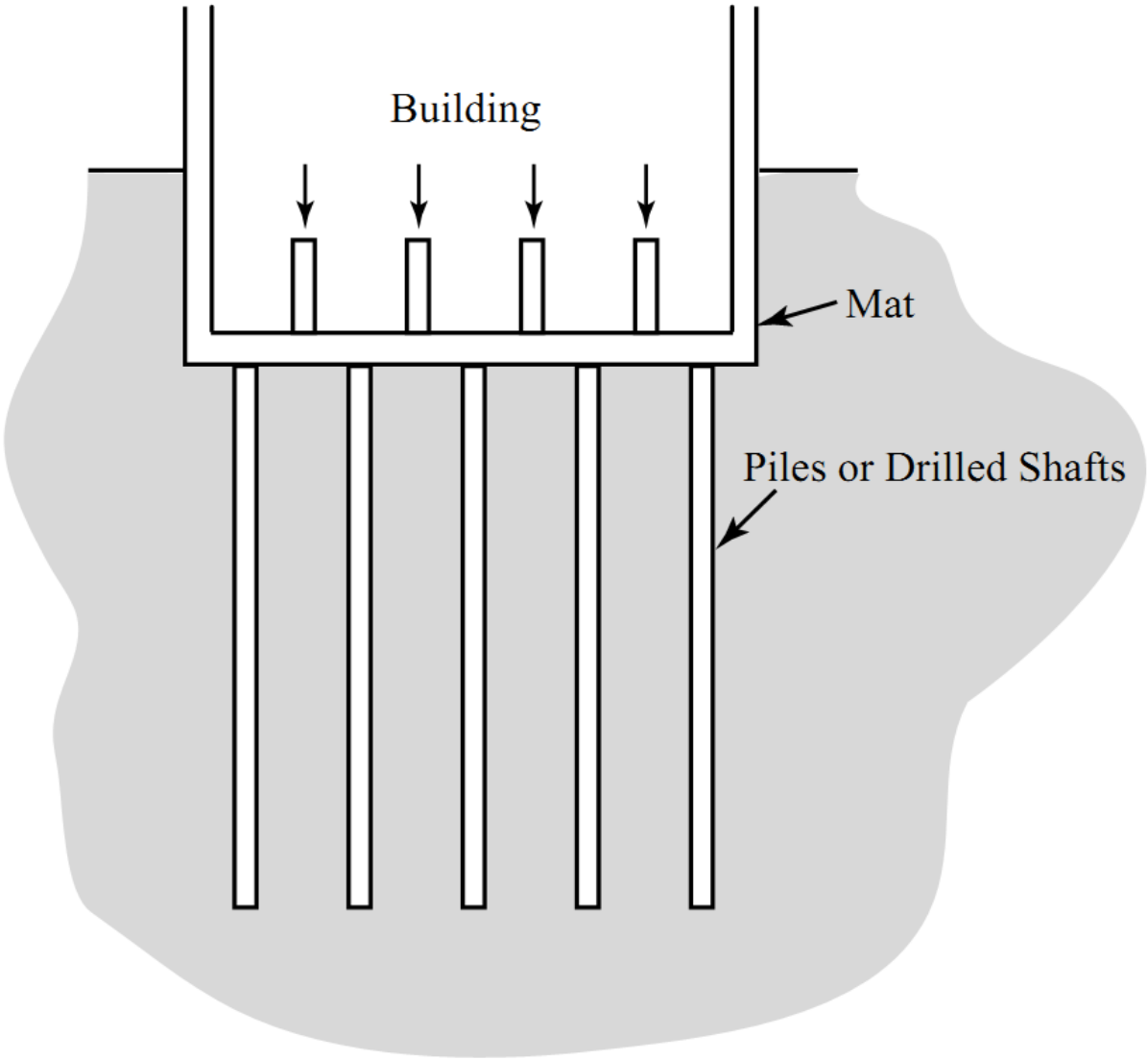
a.k.a. *caissons, drilled piles, drilled piers,*
cast-in-drilled-hole (CIDH) piles, or cast-in-situ piles





DRILLED SHAFTS

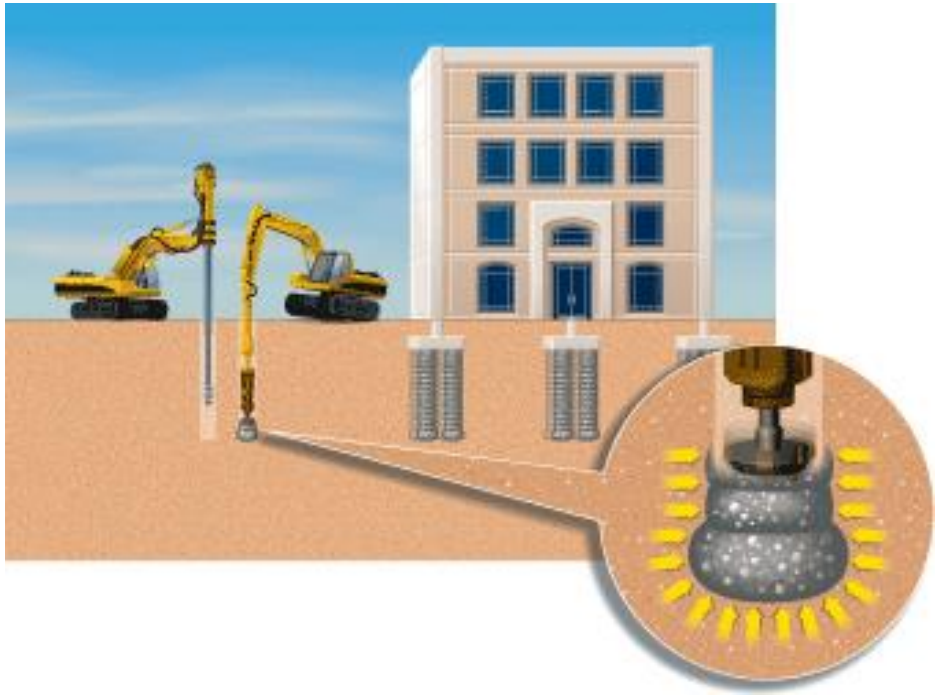
COMBINATIONS:
e.g. MAT WITH PILES OR DRILLED SHAFTS



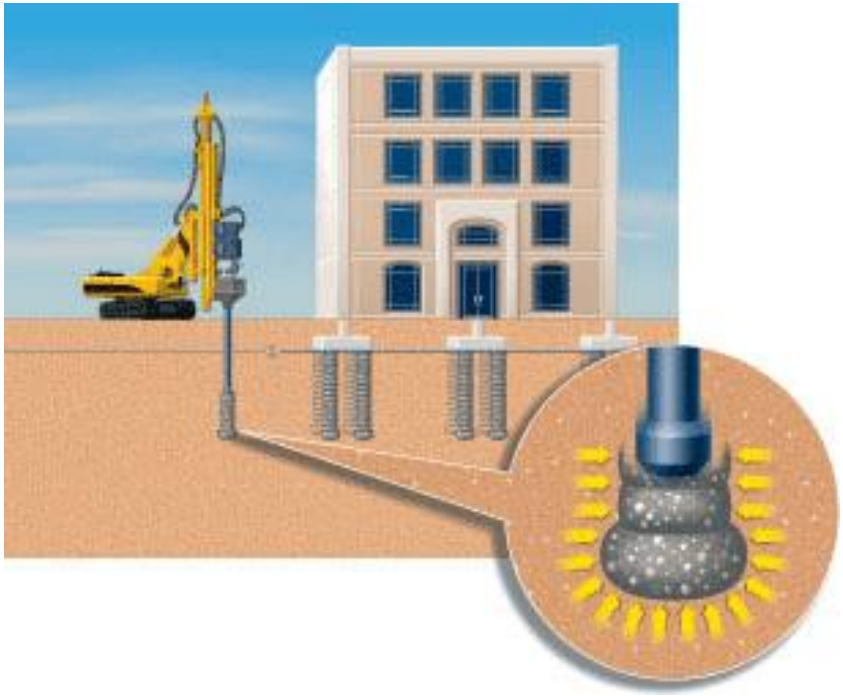
INTERMEDIATE FOUNDATIONS

Geo-Pier®

Rammed Aggregate Piers (RAPs)



Impact Piers



Sometimes referred to as *ground improvement*

RELATIVE ADVANTAGES

Type	Advantages
Shallow foundation	Economical, easy to construct, does not require specialty contractors, can be "green" if local aggregate source is found
RAP, Impact pier	Economical compared to deep foundations, "green"
Augercast piles	Less expensive, quieter and less vibration than driven piles, no casing required, can be installed with limited headroom (e.g. in existing buildings), displaced soil can be visually inspected
Driven piles	Can reach great depths, capacity is measured during installation; *"A driven pile is a tested pile" (PDCA)*, groups of piles provide redundancy
Drilled shafts	Less noise/vibration than driven piles, high resistance to lateral loads and scour, capacity is "tested" if shaft tips are pressure grouted, small footprint, no need for pile cap, visual verification of soil material

RELATIVE DRAWBACKS

Type	Drawbacks
Shallow foundation	Settlements may be too high, bearing capacity may be insufficient, small resistance to overturning, no resistance to uplift
RAP, Impact pier	Not effective if a deep soft/compressible layer governs the design
Augercast piles	Improper construction techniques can cause necking or soil “mining” leading to collapse, not suitable if cobbles/boulders are present, QA/QC is difficult
Driven piles	Expensive, vibrations can cause damage or settlement of nearby structures, noisy
Drilled shafts	Expensive, no redundancy, specialty contractors required