DEEP FOUNDATIONS

COMPARISON OF SHALLOW AND DEEP FOUNDATIONS

Description	SHALLOW	DEEP
Depth	$D_f/B \leq 1$	$D_f/B \geq 4^+$
Load Distribution	Lateral spread	Lateral and/or vertical spread - For end bearing lateral spread - For frictional vertical spread - Generally both
Construction	- Open pit construction - Easy control and the best QA/QC - Less skill labour required - Min. disturbance - During construction dewatering is required for shallow GWT	- In hole or driven - Difficult QA/QC - Very skilled labour is required - Max. disturbance - Dewatering may or may not be required
Cost	Less as compared with deep	Usually 3 times or more costly than shallow.
Structural Design Consideration	Flexural Bending	Axial Compression.
Settlement	More than that for deep foundation	Usually 50% of the shallow foundation for similar loading
Environmental Suitability	Does not suit to all environments specially for offshore sites	Suits to all environments including offshore

PILE FOUNDATION IS USED WHEN:

- ✓ The soil near the surface doesn't have sufficient bearing capacity (weak) to support the structural loads.
- ✓ The upper soil is subjected to scour or undermining as in case of foundations of bridges
- ✓ A large uplift capacity is required (the uplift capacity of shallow foundation is very limited due to lesser weight)
- ✓ A large lateral load capacity is required
- ✓ There will be a future excavation adjacent to the foundation and this may undermine the shallow foundation

PILE FOUNDATION

Classification of Piles

Piles can be classified in a number of ways as discussed below:

1. w.r.t to load transfer

- ***End bearing pile***

  If the pile is driven until it rests on a hard, impenetrable layer of soil or rock, the load of the structure is primarily transmitted axially through the pile to this layer. Such a pile is called an end-bearing pile. In the case of an end-bearing pile, care must be exercised to ensure that the hard, impenetrable layer is adequate to support the load.

- ***Friction or floating pile***

  If the pile cannot be driven to a hard stratum of soil or rock (e.g., such a stratum is located too far below the ground surface), the load of the structure must be borne primarily by skin friction or adhesion between the surface of the pile and adjacent soil. Such a pile is called friction pile.

In actual, a pile transmits its load partially through end bearing and partially through skin friction.

2. w.r.t. installation technique

- **Driven piles:** Preformed units, usually in timber, concrete or steel, driven into the soil by the blows of a hammer
- **Driven and cast-in-place piles:** Formed by driving a tube with a closed end into the soil, and filling the tube with concrete. The tube may or may not be withdrawn.
- **Jacked piles:** Steel or concrete units jacked into the soil.
- **Bored and cast-in-place piles:** Piles formed by boring a hole into the soil and filling it with concrete.
- **Composite piles:** combination of two or more of the preceding types, or combination of different materials in the same type of pile.

The first three of the above types are sometimes called displacement piles since the soil is displaced as the pile is driven or jacked into the ground.

- **Jetting piles:** Water jetting may be used to aid the penetration of a pile into a sand or sandy gravel stratum. Jetting is ineffective in firm to stiff clays or any soil containing much coarse gravel, cobbles, or boulders.

Classification of Piles

3. w.r.t. shape

- A pile can be of the following shapes

  (a) Round, (b) Square, (c) H-shape, (d) Battered, (e) Tapered, (f) Under-reamed/Bell bottom.

4. w.r.t. size of pile

- Small diameter piles: 150 – 600 mm (6″ – 2′)
- Large diameter piles: dia. > 600 mm (also called piers)
- Micro piles: dia. < 150 mm. According to M.J. Tomlinson, micropiles are bored and cast-in-place piles with a diameter of less than 300 mm.

5. w.r.t. function of pile

- Compression pile: for vertical dead loads
- Tension or anchor pile: To resist uplift due to horizontal or inclined loading
- Compaction pile: to compact loose cohesionless soils.
- Sheet pile: to control seepage as in Cofferdams

6. w.r.t material of construction

- **Timber:** Suitable for light loads or temporary works. Unsuitable for heavy loads. Subject to decay due to fluctuating water table. Liable to unseen splitting or broomming if driven too heavily.
- **Concrete**: Suitable for all ranges of loading. Concrete can be designed to suit corrosive soil conditions. Readily adaptable to various sizes and shapes. Disadvantages: additional reinforcement must be provided for handling and driving stresses; liable to unseen damage under heavy driving; delay between casting and driving.
- **Steel**: Suitable for all ranges of loading. Can be readily cut down or extended. Can be driven hard without damage. Can be driven in very long lengths by welding on additional lengths. Some types have small ground displacement. Disadvantages: subject to corrosion in marine structures and requires elaborate paint treatment and/or cathode protection; long and slender piles liable to go off line during driving.
- **Composite Piles**: Composite piles are used in ground conditions where conventional piles are unsuitable or uneconomical. A frequently used type of composite pile is the concrete and timber pile. The timber pile is terminated below the lowest ground water level and the upper portion formed in concrete.

7. w.r.t. soil volume displacement

- Large displacement piles ----displace soil volume equal to volume of pile, (Circular/sq driven piles)
- Low displacement piles ------displace small volume of soil (hollow, thin section steel piles)
- Non-displacement pile -------displace no volume of soil (bored case-in-situ piles)

Selection of Pile type

Having decided that piling is necessary, the engineer must make a choice from a variety of types and sizes. There is usually only one type of pile which is satisfactory for any particular site conditions. Here is the summary of points to be considered in choosing a particular type:

1. Driven Piles

- ***Advantages***
- Material of the pile can be inspected before it goes into the ground.
- Stable in squeezing ground, for example, soft clays, silts and peats.
- Not damaged by ground heave when driving adjacent piles.
- Constructional procedure unaffected by ground water.
- Can be readily carried above ground level, for example, through water for marine structures.
- Can be driven in very long length.
- Can increase the relative density of a granular founding stratum.

- ***Disadvantages***
- May break during hard driving, causing delays and replacement charges, or worse still may suffer major unseen damage in hard driving conditions.
- Uneconomical if amount of material in pile is governed by handling and driving stresses rather than by stresses from permanent loading.
- Noise and vibration during driving may cause nuisance or damage.
- Displacement of soil during driving piles in groups may damage adjacent structures or cause lifting by ground heave of adjacent piles.
- Cannot be driven in very large diameters.
- Cannot be driven in conditions of low headroom.
- Pile lengths up to 27 m and pile loads up to 1000 kN are usual.

Selection of Pile type

2. Driven and cast-in-place piles

- *Advantages*

- Length can be readily adjusted to suit varying level of bearing stratum.
- Tube is driven with a closed end, thus excluding ground water.
- Possible to form an enlarged base in most types.
- Reinforcement in pile is not determined from handling or driving stresses.
- Noise and vibration can be reduced in some types.

- *Disadvantages*

- ‘Necking’ or ‘waisting’ may occur in squeezing ground unless great care is taken when concreting shaft.
- Concrete shaft may be weakened if strong artesian water-flow pipes up outside of shaft when tube is withdrawn.
- Concrete cannot be inspected after completion.
- Limitations on length of driving in most types.
- Displacement of ground may damage ‘green’ concrete of adjacent piles, or cause lifting by ground heave of adjacent piles.
- Noise, vibration, and ground displacement may cause a nuisance or damage adjacent structures.
- Cannot be used in river or marine structures without special adaptation.
- Cannot be driven in very large diameters.
- Very large end bulbs cannot be made.
- Cannot be driven in conditions of very low head-room.
- Pile lengths of up to 24 m and pile loads of about to 1500 kN are common.

Selection of Pile type

3. Bored and cast-in-place piles

- ***Advantages***
  - Length can be readily varied to suit varying ground conditions.
  - Soil removed in boring can be inspected and if necessary sampled and in-situ tests made.
  - Can be installed in very large diameters.
  - End enlargements up to two or three diameters are possible in clays.
  - Material of pile is not dependent on handling or driving conditions.
  - Can be installed in very long lengths
  - Can be installed without appreciable noise or vibration.
  - Can be installed in conditions of very low head-room.
  - No risk of ground heave.
- ***Disadvantages***
  - Susceptible to ‘waisting’ or ‘necking’ in squeezing ground.
  - Concrete is not placed under ideal conditions and cannot be subsequently inspected.
  - Water under artesian pressure may pipe up pile shaft washing out cement.
  - Enlarged ends cannot be formed in cohesionless materials
  - Cannot be readily extended above ground level especially in river and marine structures.
  - Boring methods may loosen sandy or gravelly soils.
  - Sinking piles may cause loss of ground in cohesionless soils, leading to settlement of adjacent structures.
  - Pile lengths of up to 45 m with loads of up to 10,000 kN are not uncommon.

Design Criteria

There are three main criteria of Pile Design

- The pile material itself must not be over-stressed.
- There must be an adequate factor of safety against shear failure
- The settlement must be within tolerable limits.

Estimation of Pile Load Capacity

For pile capacity estimation, two basis

- Pile capacity in Granular Soils
- Pile capacity in Cohesive Soils

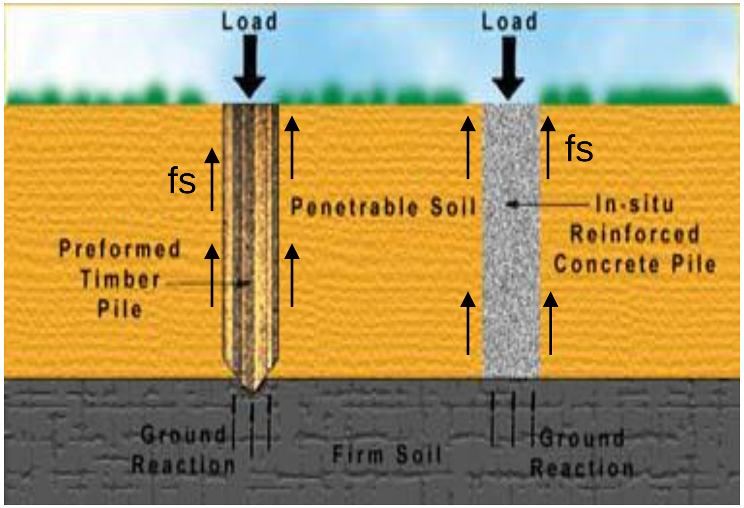
The total pile capacity is expressed as

$$Q_u = Q_b + Q_s$$
$$= q_b A_b + f_s A_s$$

Q_u = ultimate pile capacity

Q_b = End bearing Capacity, q_b = end bearing, A_b = area of pile base = $(\pi/4)D^2$

Q_s = Skin friction capacity, f_s = unit skin friction, A_s= surface area of pile shaft = πDL



Load Transfer Mechanism

- **Load is partly taken by shaft, Q_s, and partly by end, Q_b**

- **The frictional resistance is fully mobilized at low relative displacement b/w soil and Pile at about 0.5% to 1% of pile dia. or 5-10 mm settlement.**

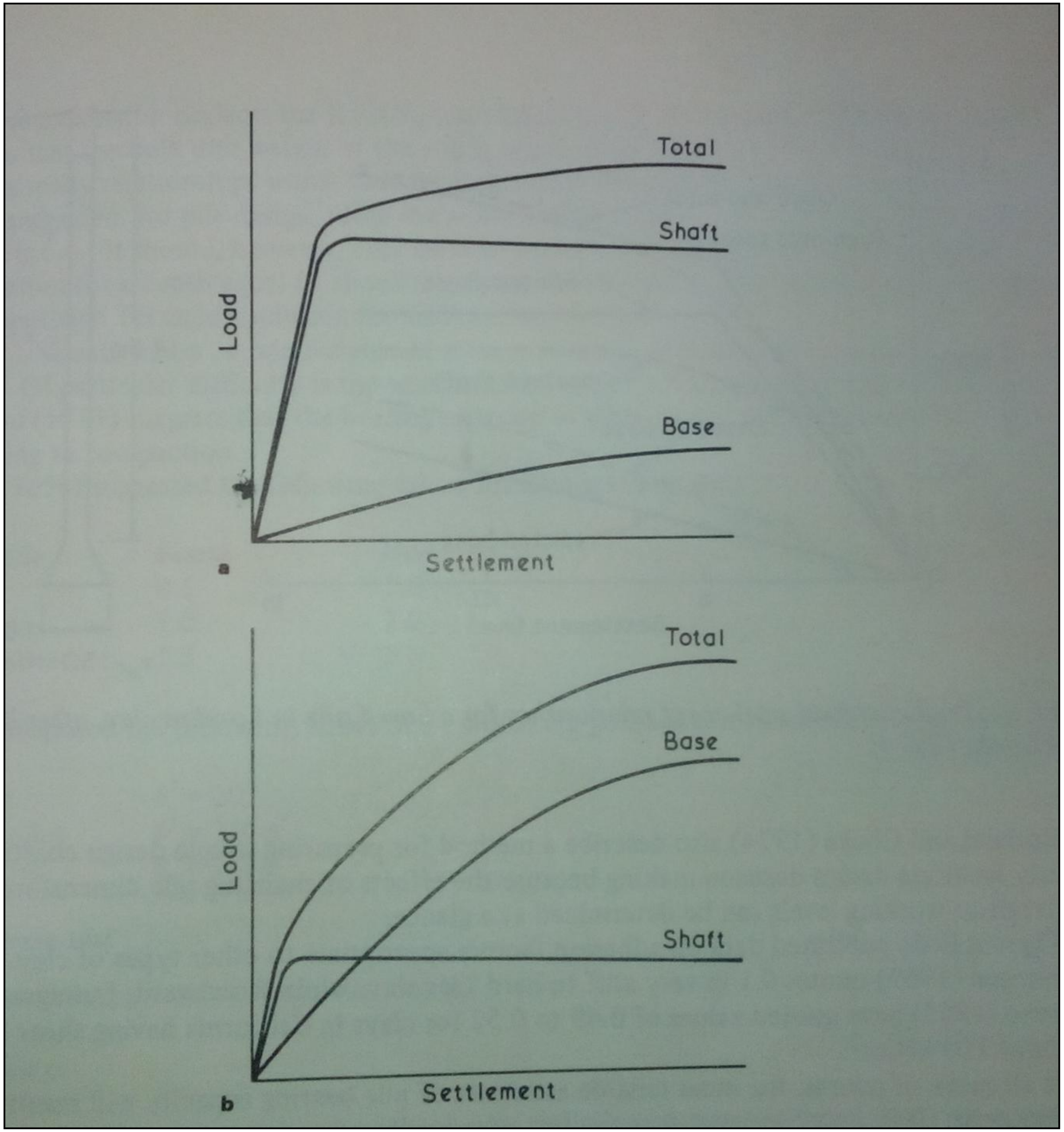
- **The end bearing is fully mobilized at larger settlement of about 10-20% of pile dia.**

- **In case of deep foundation, the soil fails in punching mode under the pile base.**

Mobilization of Qs & Qb with settlement of pile

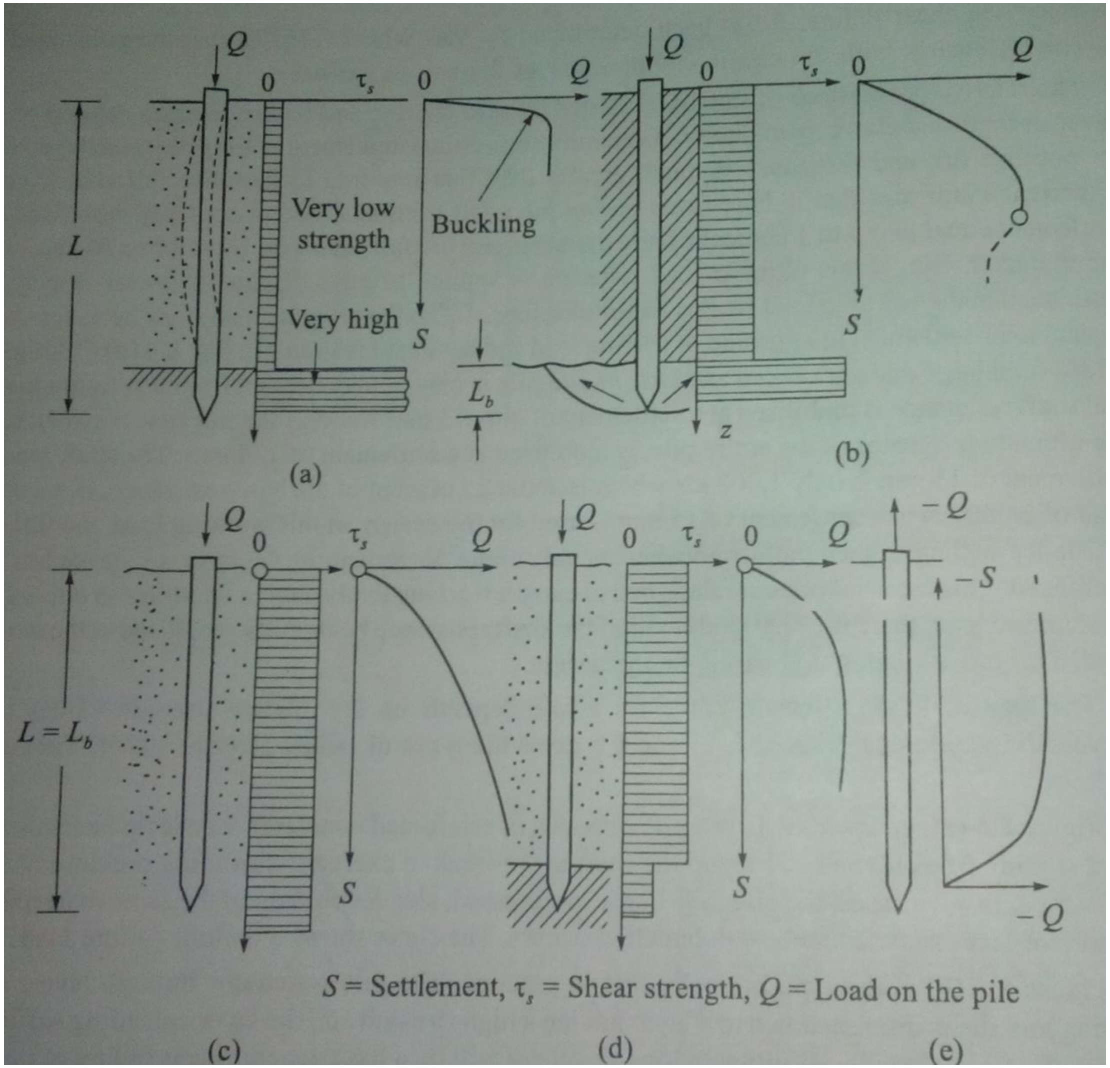
Straight Shaft Piles

Under reamed or belled piles



Behavior of Pile in different soils

a. **Pile resting on hard bed; buckling of pile in weak surrounding soil**
b. **General shear failure in strong base soil**
c. **Soil of uniform strength; load taken by both Q_s and Q_b, no definite failure**
d. **Low strength of base soil; load mainly taken by shaft**
e. **Uplift resistance is only due to skin resistance in downward direction, point resistance is zero**



Factor of Safety in Pile Design

- The allowable load is governed solely from consideration of tolerable settlement.
- The working load for all pile types in all soils is taken equal to sum of base resistance plus shaft resistance divided by a suitable safety factor which is normally taken as 2.5~3

$$Q_a = (Q_b + Q_s)/FOS$$

- In case the value of Q_b and Q_s can be obtained independently, the allowable load can be taken as

$$Q_a = Q_b/3 + Q_s/1.5$$

As Q_s is mobilized at very small settlement usually 5~8 mm, whereas Q_b is mobilized at large settlement.