# Civil Engineering Construction

Chapter 3

## Deep Foundation

Dr Mohamad Syazli Fathi

Department of Civil Engineering
UTM RAZAK School of Engineering & Advanced Technology
UTM *International Campus*

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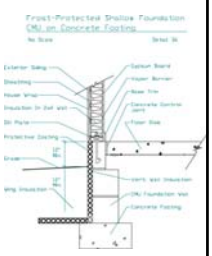
## TYPES OF FOUNDATIONS

- Foundations can be classified into two categories :

1. Shallow foundations.



2. Deep foundations

## Deep foundations.

- The foundations constructed below ground level with some arrangements such as piles, wells, etc. at their base are called deep foundations.
- Deep foundations are classified into the following types:
  - Pile foundation
  - Well foundation
  - Caisson foundation

## Pile foundation.

- A foundation consisting of spread footing supported at their base is called a piles foundation. Piles distribute the load of structure to the soil in contact either by friction alone or by friction combined with bearing at their ends.

**Suitability.**

Pile foundation is suitable under the following situations :

- **i.** When the soil is very soft and solid bed is not available at a reasonable depth to keep the bearing power within safe limits.
- ii. When provision of pad and raft foundations becomes very expensive.
- iii. When the structure carries heavy concentrated loads.
- iv. When it is necessary to construct a building along the sea-shore or river bed.

Piles are generally classified into two categories :

- 1. According to function, e.g bearing piles, friction piles, friction-cum-bearing piles, batter piles, guide piles, sheet piles, etc.
- 2. According to composition or material of construction, e.g timber piles, concrete piles, sand piles, steel piles, etc.

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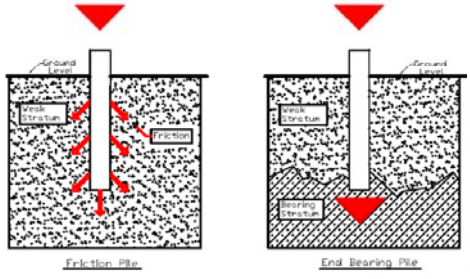

## Classification of piles according to their function.

i. **Bearing piles**. The piles rest on hard strata and act as columns to bear the load of the structure. These piles are used to bear vertical loads and transfer the load to the hard stratum lying underneath. See figure.

ii. **Friction piles.** The piles do not rest on hard strata and bear on frictional resistance between their outer surface and the soil in contact. These piles are used when the soil is soft and no hard strata available to a certain depth. The piles are long in length and the surfaces are roughened or increases surface area to increase frictional resistance. See figure.

iii. **Friction-cum-piles.** The piles rest on hard strata and resist the structural load partly by bearing and partly by friction. These piles are used when bearing capacity of soil strata lying under them is not sufficient to resist load of the structure. See figure.

iv. **Batter piles.** The piles are driven inclined to resist inclined loads.

v. **Guide piles**. These piles are used in the formation of cofferdams which temporarily constructed to provide foundations under water.

Vi. **Sheet piles.** The piles of thin steel sheets, driven in the ground to inclose soft material, used in cofferdams. The piles are not required to carry any load but should be strong to take lateral pressure of earth filling, water, etc.

## End bearing piles

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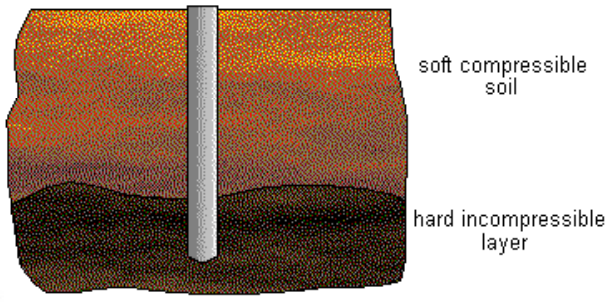

## End bearing piles

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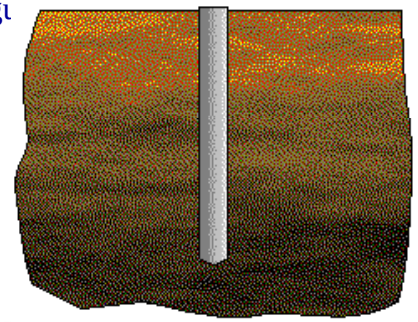
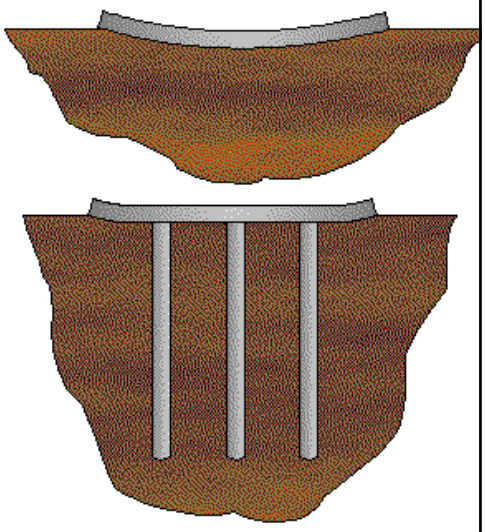


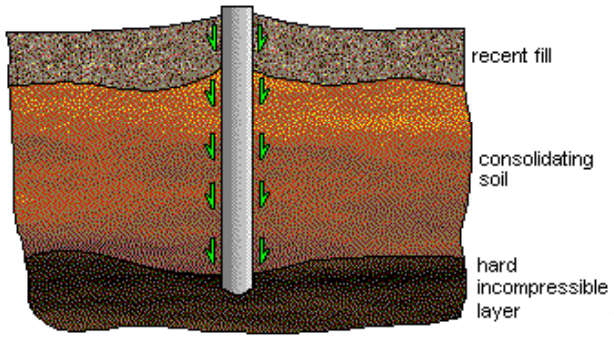

## Settlement reducing piles

- Settlement reducing piles are usually incorporated beneath the central part of a raft foundation in order to reduce differential settlement to an acceptable level. Such piles act to reinforce the soil beneath the raft and help to prevent dishing of the raft in the centre



# Piles in fill

Piles that pass through layers of moderately- to poorly-compacted fill will be affected by **negative skin friction**, which produces a downward drag along the pile shaft and therefore an additional load on the pile. This occurs as the fill consolidates under its own weight.




## Classification of piles according to their composition or material of construction

- **Timber piles**. The piles made of wood, should be free from defects, decay, etc and it should be well seasoned. The piles can be circular or square in cross-section. Top of these piles is provided with an iron ring to prevent it from splitting under blows of hammer. The bottom is fitted with an iron shoe to facilitate sinking of piles. These piles are driven by blows of hammer of a pile driving machine.
- Used for buildings, bridges and cofferdams but is not recommended to be used in sea water.

- **Advantages of timber piles**:
  i. Less expensive as timber available can be used after suitable treatment.
  ii. Can be made longer in lengths by joining the individual pieces easily.
  iii. Cutting of these piles is easy.
  iv. Can be driven easily with lighter machinery.
- **Disadvantages :**
  i. The piles deteriorate by action of water and insects.
  ii. Lesser load bearing capacity
  iii. A number of small individual units require to construct long piles; this entails lot of joining work as such the cost becomes high in constructing the piles.

## Concrete piles

- The piles are made of cement concrete, strong, durable and can bear more load than timber piles. They are free from defects and cannot be attacked by insect, white-ant, etc. The piles are fire-proof and water-proof. Concrete piles are classified into two types:
  1. Pre-cast piles.
  2. Cast-in-situ piles.

# Pre-cast piles

- These are R.C.C piles which are square, circular or octagonal in cross-section.
- Advantages include high strength and resistance to decay.
- It's the heaviest, brittle and lack of tensile strength.
- The construction requires care in handling and drivin to prevent pile damage.

- **Advantages of Pre-cast Concrete Piles:**
  i. Best concrete can be prepared by proper workmanship. Any defect can be repaired immediately.
  ii. The reinforcement remains in proper position and does not displaced.
  iii. The concrete only withstands loads after complete curing has taken place. They can be cast beforehand and quick driving progress can be ensured.
  iv. More convenient when driven through wet conditions.
  v. Suitable when part of their length is to remain exposed.
  vi. Not affected by other additional forces which act on the piles while adjacent piles are driven.
- **Disadvantages :**
  i. Heavy and difficult to transport.
  ii. Lapping of additional length means extra cost, labour ang energy.
  iii. Heavier in section to withstand holding stresses.
  iv. The shocks of driving make the weaker.

- **Cast-in-situ piles**. This type of piles is constructed in its location in a bore hole prepared for this field. The operation consists of boring a hole, filling it with concrete or steel reinforcement and concrete. Examples are simplex pile, pedestal or bulb pile, Frankie pile, Raymond concrete pile, etc. See figures.
- **Advantages of Cast-in-situ piles :**
  i. Less wastage of material as exact length of pile is cast.
  ii. Time spent on curing is saved.
  iii. Can bear heavier loads by improving their X-sectional profile, eg, pedestial pile.
- **Disadvantages:**
  i. Good quality concrete cannot be easily obtained due to unusual height of dumping.
  ii. The reinforcements are liable to get displaced.
  iii. They cannot be used under water.
  iv. The green concrete loses strength after coming in contact with the soil.
  v. The shells are affected by casting additional piles adjacent to them.

- **Sand piles**. The piles consisting of sand filled in bore holes, formed by digging holes which are then filled with sand and compacted. Top of the pile is covered with concrete. Cheap, easily constructed and only for light loads.
- **Steel piles are of steel section**. Useful where driving conditions are difficult and other types of piles are not suitable. Usually used for building and bridge foundations. The piles are in form of I, U, H sections.
- **Steel piles** are available in the following forms.
  i. Steel pin piles
  ii. Sheet piles
  iii. Disc piles
  iv. Screw piles.

- **Pile Driving.** The operation of forcing a pile into the ground without any previous excavation is called pile driving:
  1. Drop – hammer method;
  2. Steam – hammer method;
  3. Boring;
  4. Screwing;
  5. Water jet method.
- **Drop hammer method**. It's the simplest method of pile driving. A hammer is dropped on the head of the pile and is guided during its fall in stages. The modern version is illustrated in figure.
- **Steam-hammer method**. A heavy hammer is dropped on to the pile at a certain height in quick succession. Steam hammers are available in single acting or double acting. These hammers are specially used for driving sheets piles where small variations are required to be set up in the piles.

# Types of pile construction

**Displacement piles**

- Displacement piles cause the soil to be displaced radially as well as vertically as the pile shaft is driven or jacked into the ground

**Non-displacement piles**

- With non-displacement piles (or replacement piles), soil is removed and the resulting hole filled with concrete or a precast concrete pile is dropped into the hole and grouted in.

# Displacement piles

1. **Totally preformed displacement piles**
2. **Driven and cast-in-place displacement piles**
3. **Helical (screw) cast-in-place displacement piles**

**Methods of installation**

- Sands and granular soils tend to be compacted by the displacement process, whereas clays will tend to heave. Displacement piles themselves can be classified into different types, depending on how they are constructed and how they are inserted.

# Totally preformed displacement piles

- These can either be of precast concrete;
  - full length reinforced (prestressed)
  - jointed (reinforced)
  - hollow (tubular) section
  - or they can be of steel of various section.

**Driven and cast-in-place displacement piles**

- This type of pile can be of two forms. The first involves driving a temporary steel tube with a closed end into the ground to form a void in the soil which is then filled with concrete as the tube is withdrawn. The second type is the same except the steel tube is left in place to form a permanent casing.

**Helical (screw) cast-in-place displacement piles**

- This type of construction is performed using a special type of auger. The soil is however compacted, not removed as the auger is screwed into the ground. The auger is carried on a hollow stem which can be filled with concrete, so when the required depth has been reached concrete can be pumped down the stem and the auger slowly unscrewed leaving the pile cast in place.

# Methods of installation

Displacements piles are either driven or jacked into the ground. A number of different methods can be used.

1. **Dropping weight**
2. **Diesel hammer**
3. **Vibratory methods of pile driving**
4. **Jacking methods of insertion**

# Dropping weight

- The **dropping weight or drop hammer** is the most commonly used method of insertion of displacement piles.
- A weight approximately half that of the pile is raised a suitable distance in a guide and released to strike the pile head.
- When driving a hollow pile tube the weight usually acts on a plug at the bottom of the pile thus reducing any excess stresses along the length of the tube during insertion.

# Dropping weight

- Variants of the simple drop hammer are the **single acting and double acting hammers**.
- These are mechanically driven by steam, by compressed air or hydraulically.
- In the single acting hammer the weight is raised by compressed air (or other means) which is then released and the weight allowed to drop.
- This can happen up to 60 times a minute.
- The double acting hammer is the same except compressed air is also used on the down stroke of the hammer.
- This type of hammer is not always suitable for driving concrete piles however.
- Although the concrete can take the compressive stresses exerted by the hammer the shock wave set up by each blow of the hammer can set up high tensile stresses in the concrete when returning. This can cause the concrete to fail. This is why concrete piles are often prestressed.

# Diesel hammer

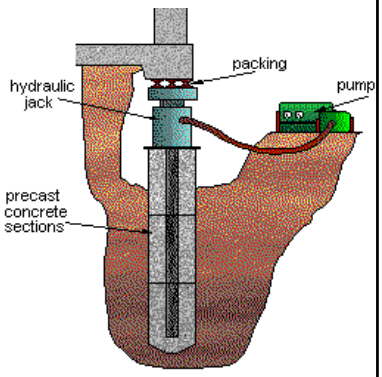
- Rapid controlled explosions can be produced by the diesel hammer.
- The explosions raise a ram which is used to drive the pile into the ground.
- Although the ram is smaller than the weight used in the drop hammer the increased frequency of the blows can make up for this inefficiency.
- This type of hammer is most suitable for driving piles through non-cohesive granular soils where the majority of the resistance is from end bearing.

# Vibratory methods of pile driving

- Vibratory methods can prove to be very effective in driving piles through non cohesive granular soils.
- The vibration of the pile excites the soil grains adjacent to the pile making the soil almost free flowing thus significantly reducing friction along the pile shaft.
- The vibration can be produced by electrically (or hydraulically) powered contra-rotating eccentric masses attached to the pile head usually acting at a frequency of about 20-40 Hz.
- If this frequency is increased to around 100 Hz it can set up a longitudinal resonance in the pile and penetration rates can approach up to 20 m/min in moderately dense granular soils. However the large energy resulting from the vibrations can damage equipment, noise and vibration propagation can also result in the settlement of nearby buildings.

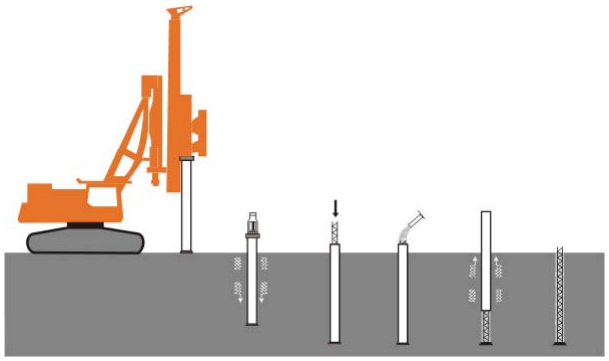
# Jacking methods of insertion

- Jacked piles are most commonly used in underpinning existing structures. By excavating underneath a structure short lengths of pile can be inserted and jacked into the ground using the underside of the existing structure as a reaction.



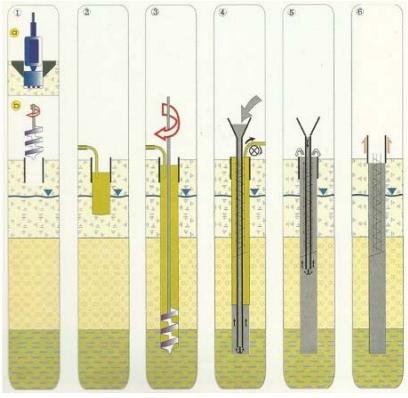
# Non-displacement piles

1. **Small diameter bored cast-in-place piles**
2. **Large diameter bored cast-in-place piles**
3. **Partially preformed piles**
4. **Grout or concrete intruded piles**



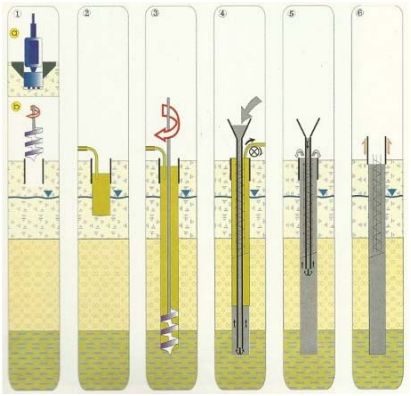
# Non-displacement piles

1. With non-displacement piles soil is removed and the resulting hole filled with concrete or sometimes a precast concrete pile is dropped into the hole and grouted in.
2. Clays are especially suitable for this type of pile formation as in clays the bore hole walls only require support close to the ground surface.



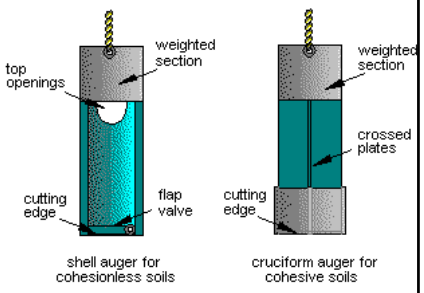
# Non-displacement piles

3. When boring through more unstable ground, such as gravels, some form of casing or support, such as a bentonite slurry, may be required.
4. Alternatively, grout or concrete can be intruded from an auger rotated into a granular soil. There are then essentially four types of non displacement piles.
5. This method of construction produces an irregular interface between the pile shaft and surrounding soil which affords good skin frictional resistance under subsequent loading.



# Small diameter bored cast-in-place piles

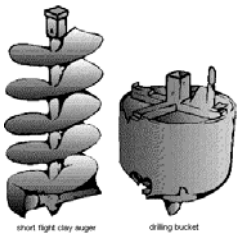
- These tend to be 600mm or less in diameter and are usually constructed by using a tripod rig. The equipment consists of a tripod, a winch and a cable operating a variety of tools. The basic tools are shown in this diagram.
- In granular soils, the basic tool consists of a heavy cylindrical shell with a cutting edge and a flap valve at the bottom. Water is necessary to assist in this type of excavation. By working the shell up and down at the bottom of the bore hole liquefaction of the soil takes place (as low pressure is produced under the shell as the liquified soil is rapidly moved up) and it flows into the shell and can be winched to the surface and tipped out. There is a danger when boring through granular soil of over loosening the material at the sides of the bore. To prevent this a temporary casing should be advanced by driving it into the ground.




- In cohesive soils, the borehole is advanced by repeatedly dropping a cruciform-section tool with a cylindrical cutting edge into the soil and then winching it to the surface with its burden of soil. Once at the surface the clay which adheres to the cruciform blades is paired away.

## Large diameter bored cast-in-place piles

- Large boreholes from 750mm up to 3m diameter (with 7m under-reams) are possible by using rotary drilling machinery. The augering plant is usually crane or lorry mounted.
- A spiral or bucket auger as shown in this diagram is attached to a shaft known as a Kelly bar (a square section telescopic member driven by a horizontal spinner). Depths of up to 70m are possible using this technique. The use of a bentonite slurry in conjunction with bucket auger drilling can eliminate some of the difficulties involved in drilling in soft silts and clays, and loose granular soils, without continuous support by casing tubes.




- One advantage of this technique is the potential for under reaming. By using an expanding drilling tool the diameter at the base of the pile can be enlarged, significantly increasing the end bearing capacity of the pile. However, under-reaming is a slow process requiring a stop in the augering for a change of tool and a slow process in the actual under-reaming operation. In clay, it is often preferable to use a deeper straight sided shaft.

## Partially pre-formed piles

- This type of pile is particularly suitable in conditions where the ground is waterlogged, or where there is movement of water in an upper layer of the soil which could result in cement being leached from a cast-in-place concrete pile.
- A hole is bored in the normal way and annular sections are then lowered into the bore hole to produce a hollow column.
- Reinforcement can then be placed and grout forced down to the base of the pile, displacing water and filling both the gap outside and the core inside the column.

## Grout- or concrete-intruded piles

- The use of continuous flight augers is becoming a much more popular method in pile construction.
- These piles offer considerable environmental advantages during construction.
- Their noise and vibration levels are low and there is no need for temporary borehole wall casing or bentonite slurry making it suitable for both clays and granular soils. The only problem is that they are limited in depth to the maximum length of the auger (about 25m). The piles are constructed by screwing the continuous flight auger into the ground to the required depth leaving the soil in the auger. Grout (or concrete) can then be forced down the hollow shaft of the auger and then continues building up from the bottom as the auger with its load of spoil is withdrawn. Reinforcement can then be lowered in before the grout sets.
- An alternative system used in granular soils is to leave the soil in place and mix it up with the pressured grout as the auger is withdrawn leaving a column of grout reinforced earth.

## Factors influencing choice of pile

There are many factors that can affect the choice of a piled foundation. All factors need to be considered and their relative importance taken into account before reaching a final decision.

1. **Location and type of structure**
2. **Ground conditions**
3. **Durability**
4. **Cost**

## Location and type of structure

1. For structures over water, such as wharves and jetties, driven piles or driven cast-in-place piles (in which the shell remains in place) are the most suitable.
2. On land the choice is not so straight forward.
3. Driven cast-in-place types are usually the cheapest for moderate loadings. However, it is often necessary for piles to be installed without causing any significant ground heave or vibrations because of their proximity to existing structures. In such cases, the bored cast-in-place pile is the most suitable.
4. For heavy structures exerting large foundation loads, large-diameter bored piles are usually the most economical.
5. Jacked piles are suitable for underpinning existing structures.

## Ground conditions

- Driven piles cannot be used economically in ground containing boulders, or in clays when ground heave would be detrimental.
- Similarly, bored piles would not be suitable in loose water-bearing sand, and under-reamed bases cannot be used in cohesionless soils since they are susceptible to collapse before the concrete can be placed.

# Durability

- This tends to affect the choice of material. For example, concrete piles are usually used in marine conditions since steel piles are susceptible to corrosion in such conditions and timber piles can be attacked by boring molluscs.
- However, on land, concrete piles are not always the best choice, especially where the soil contains sulphates or other harmful substances.

# Cost

- In coming to the final decision over the choice of pile, cost has considerable importance.
- The overall cost of installing piles includes the actual cost of the material, the times required for piling in the construction plan, test loading, the cost of the engineer to oversee installation and loading and the cost of organisation and overheads incurred between the time of initial site clearance and the time when construction of the superstructure can proceed.

## Pile groups

- Piles are more usually installed in groups, rather than as single piles.
- A pile group must be considered as a composite block of piles and soil, and not a multiple set of single piles.
- The capacity of each pile may be affected by the driving of subsequent piles in close proximity.
- Compaction of the soil between adjacent piles is likely to lead to higher contact stresses and thus higher shaft capacities for those piles.
- The ultimate capacity of a pile group is not always dependent on the individual capacity of each pile.
- When analysing the capacity of a pile group 3 modes of failure must be considered.
  1. **Single pile failure**
  2. **Failure of rows of piles**
  3. **Block failure**

## Pile groups

- The methods of insertion, ground conditions, the geometry of the pile group and how the group is capped all effect how any pile group will behave.
- If the group should fail as a block, full shaft friction will only be mobilised around the perimeter of the block and so any increase in shaft capacity of individual piles is irrelevant.
- The area of the whole base of the block must be used in calculating the end bearing capacity and not just the base areas of the individual piles in the group.
- Such block failure is likely to occur if piles are closely spaced or if a ground-contacting pile cap is used.
- Failure of rows of piles is likely to occur where pile spacing in one direction is much greater than in the perpendicular direction.