Foundation

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What is Foundation?

Foundation is the element of a structure that serves to support the loads super-imposed to it through the transmitting elements (such as columns).

In addition, foundation also serves some other functions, such as:

1. Prevent settlement (including differential settlement) of a structure
2. Prevent possible movement of structure due to periodic shrinkage and swelling of subsoil
3. Allow building over water or water-logged ground
4. Resist uplifting or overturning forces due to wind
5. Resist lateral forces due to soil movement
6. Underpin (support) existing or unstable structures

What is Foundation?

The performance or choices of foundation depends on a number of factors, these include:

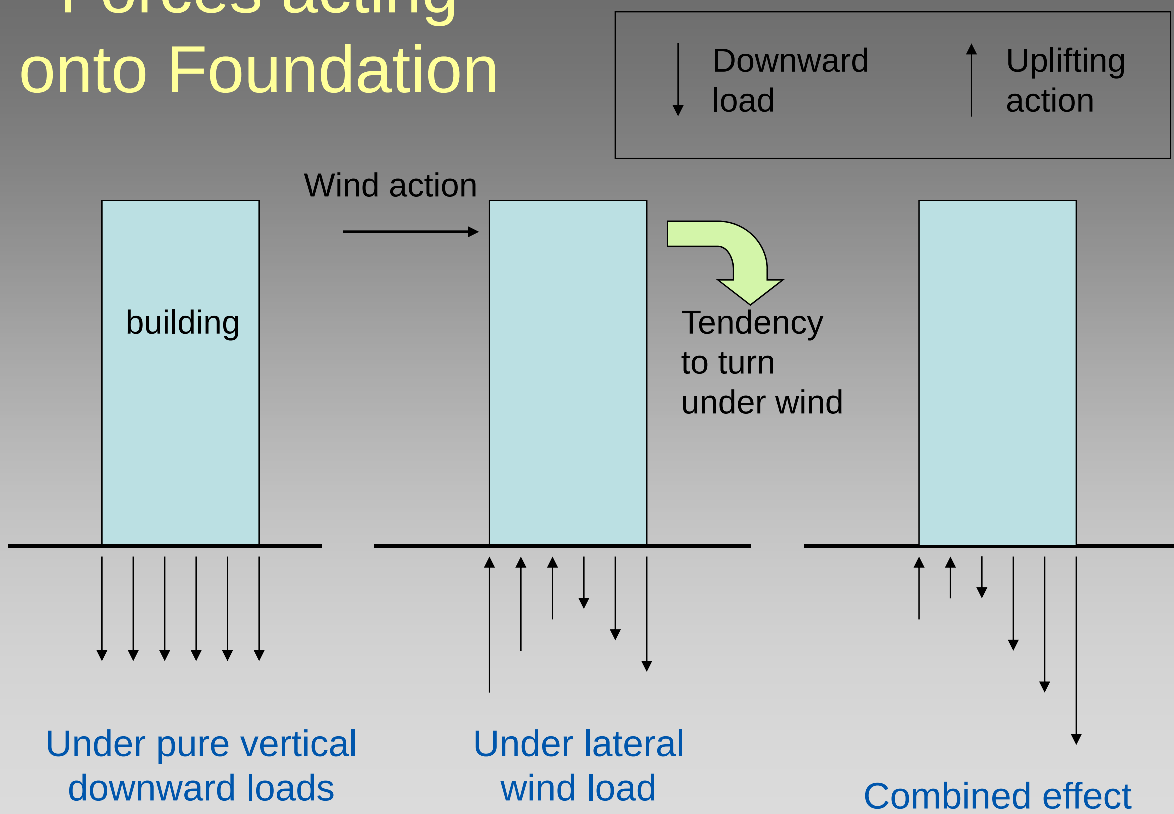
- Nature of sub-soil
- Materials used for the foundation
- Economical consideration of using a right kind of foundation
- Layout of the structure (building/floor plan, positioning loads etc.)
- Conditional of the site (location and sufficient work space)

Classification of Foundation

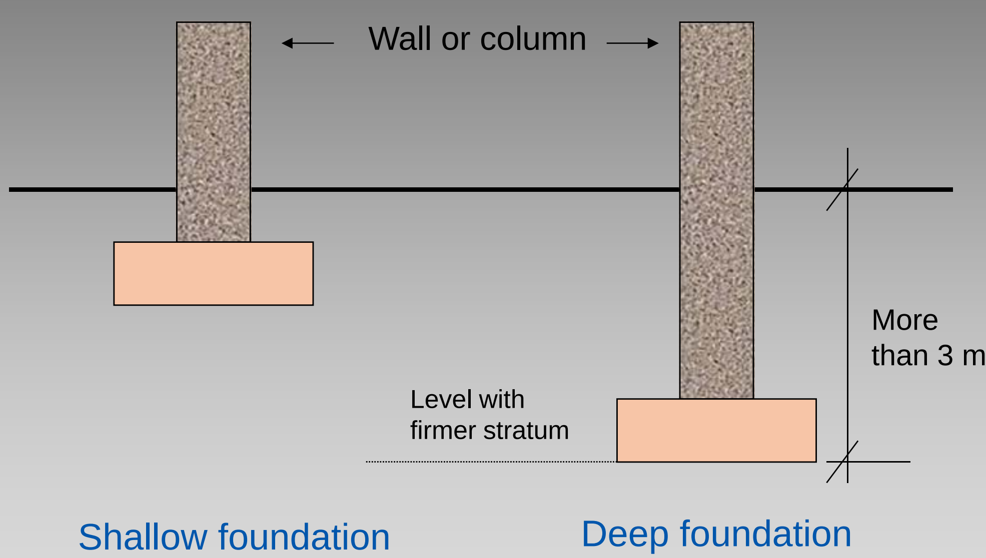
Foundation in general can be classified into a number of ways, such as:

1. Simple, Shallow and Deep foundation
2. Pad/strip type and piled foundation

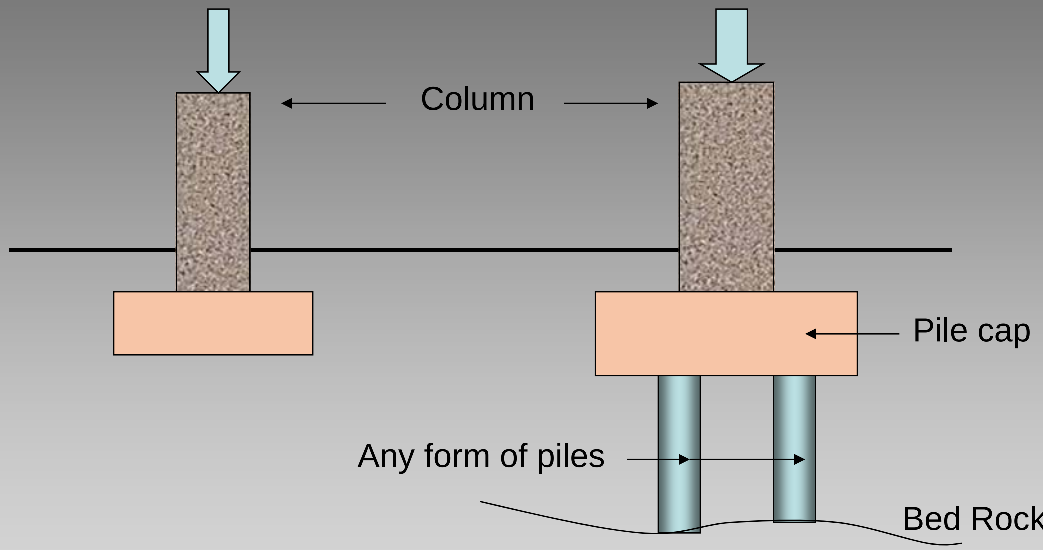
Forces acting onto Foundation



Examples of Shallow Foundation



Shallow and Piled Foundation



Pad foundation

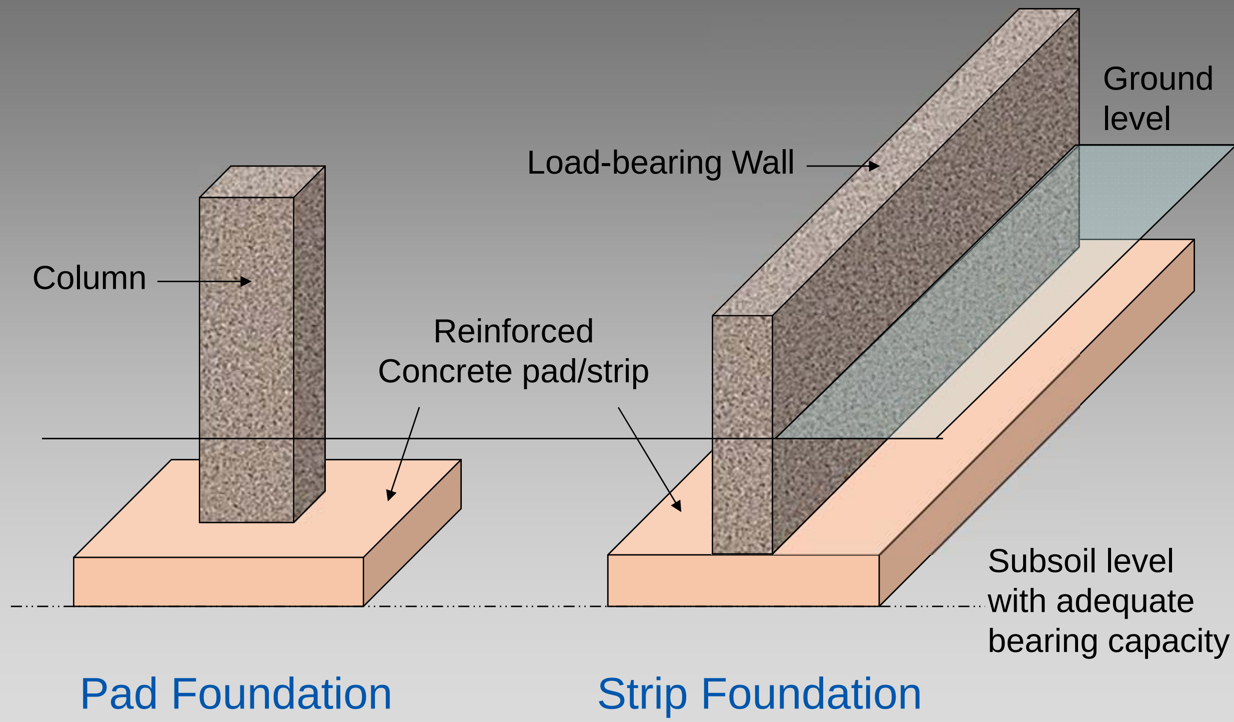
piled foundation

Shallow Foundation

This type of foundation usually refers to those being rested on stratum with adequate bearing capacity and laid less than 3m below ground level. Common examples include pad, strip or raft foundations.

The selection of the right type of shallow foundation normally depend on the magnitude and disposition of the structural loads and the bearing capacity of subsoil. A combination of two or three type of shallow foundation in one single structure is not uncommon.

Types of Shallow Foundation

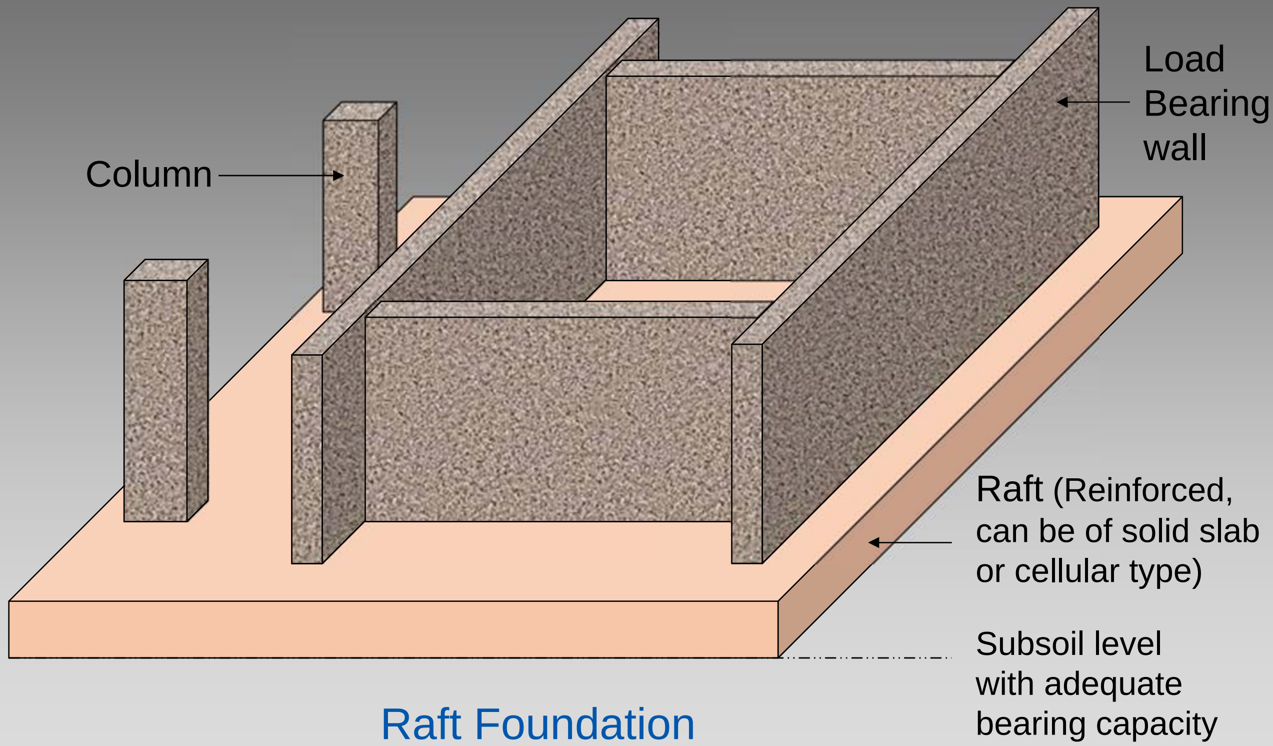


Raft Foundation

Raft foundation is a large combined thick slab designed to seat and support the whole or a large part of a structure.

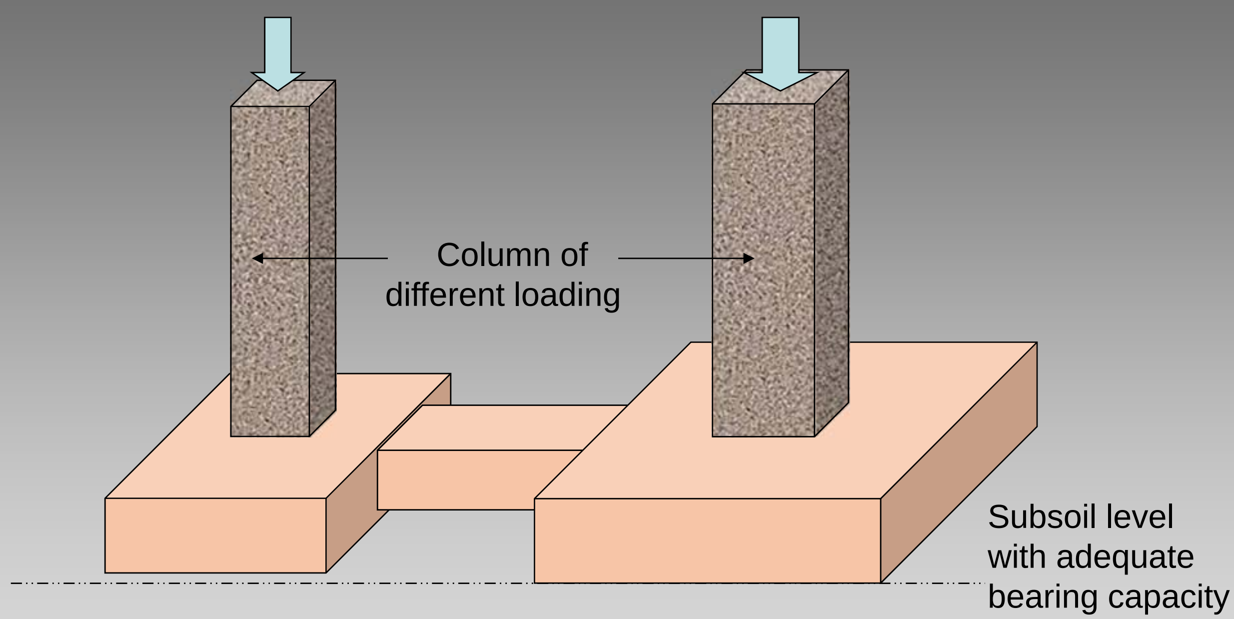
A raft is usually used when subsoil is weak, or columns are closely located and with deviated loadings. It also serves as a transfer slab to combine and tie up all the vertical loading elements to the plate-form foundation. By doing so, differential settlement can be avoided.

Types of Shallow Foundation



Raft Foundation

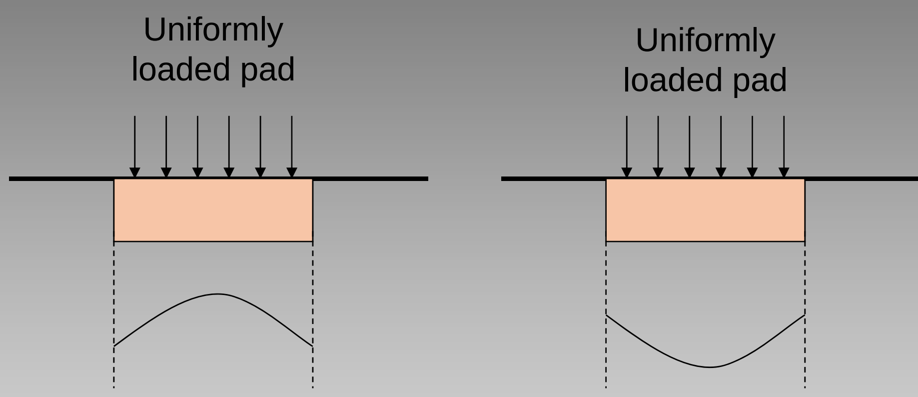
Balanced base Foundation



Pad Foundation with tie-beam balancing the tilting effect due to different in turning moment

Loading condition of foundation

(pressure distribution in different soil)

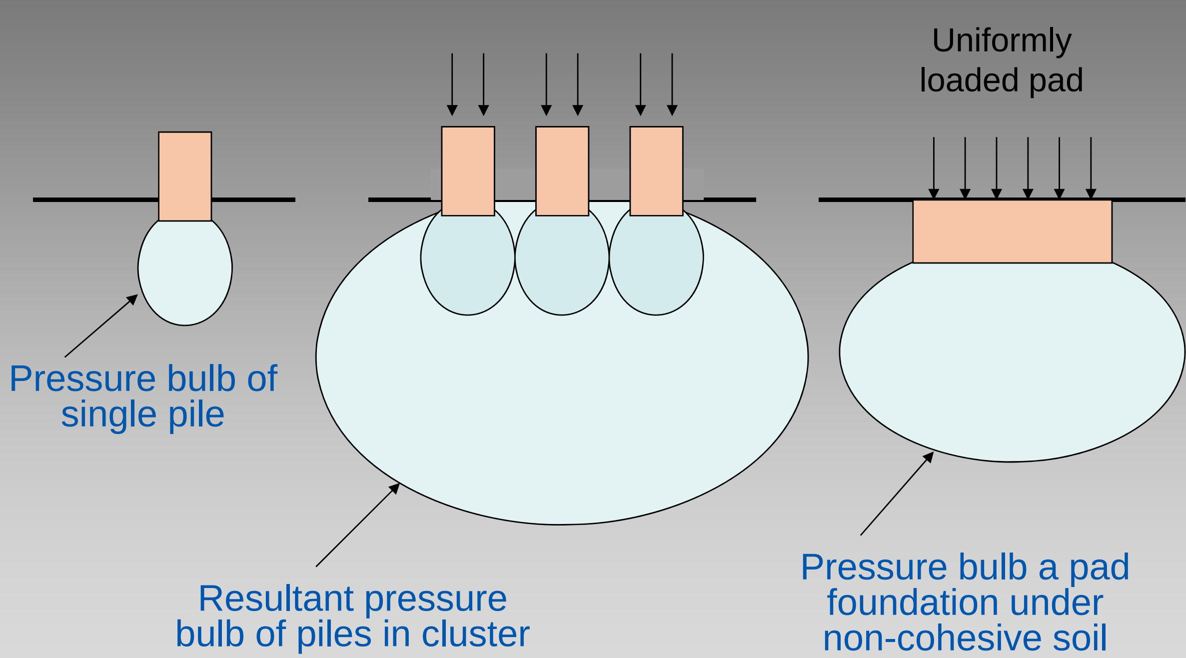


Pressure distribution
in cohesive soil

Pressure distribution
in non-cohesive soil

Loading condition of foundation

(pressure bulb)



Piled Foundation

Piled foundation is a form of foundation using piles to transfer the loads of a structure down to a firm soil stratum with sufficient load-taking capacity.

Materials for the piles can be of:

- timber
- precast concrete (sometimes also pre-stressed)
- In-situ reinforced concrete
- steel piles in ‘H’ or circular section

Piled Foundation

The design, performance and options of piled foundation depends on several factors, such as:

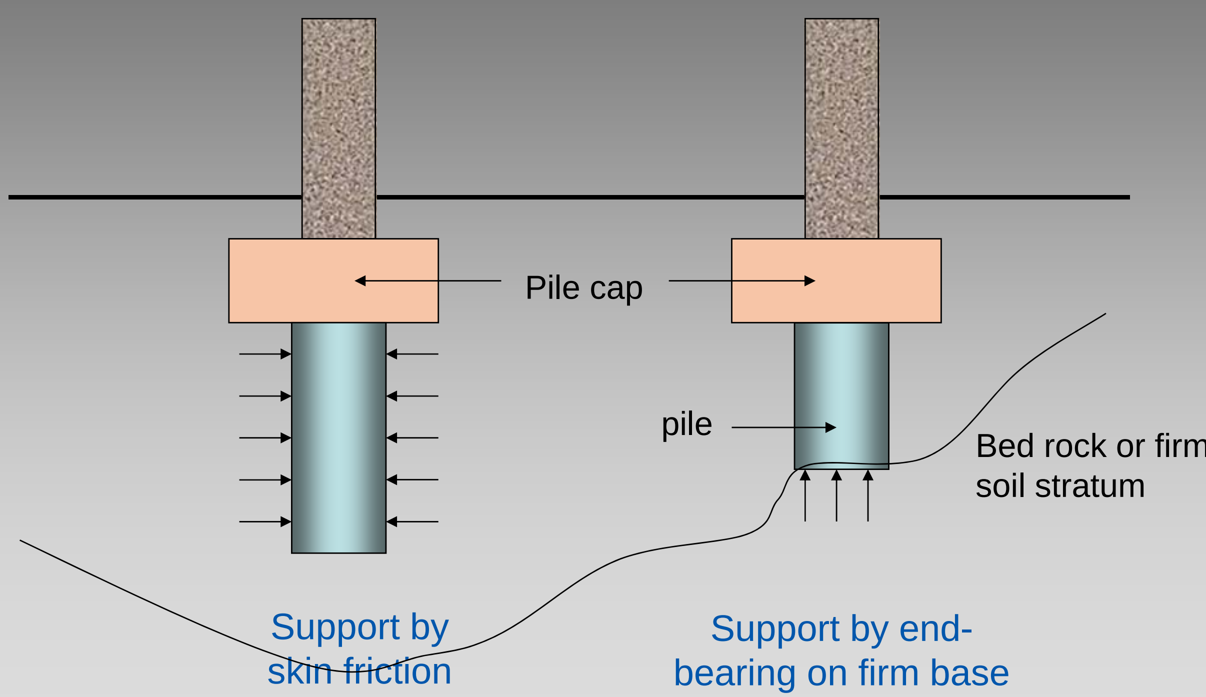
- Depth of sound subsoil
- Constituents and nature of subsoil (e.g. existing of boulders, cohesive/non-cohesive nature of soil etc.)
- Physical environment of site (e.g. accessibility, space or headroom for the operation of equipment)
- Speed of work
- Loading condition of pile (compression/tension pile)
- Efficacy of using a right kind of pile (e.g. whether use lesser piles in larger diameter instead of more small-diameter piles)
- Layout of the structure

Loading Supports to Pile

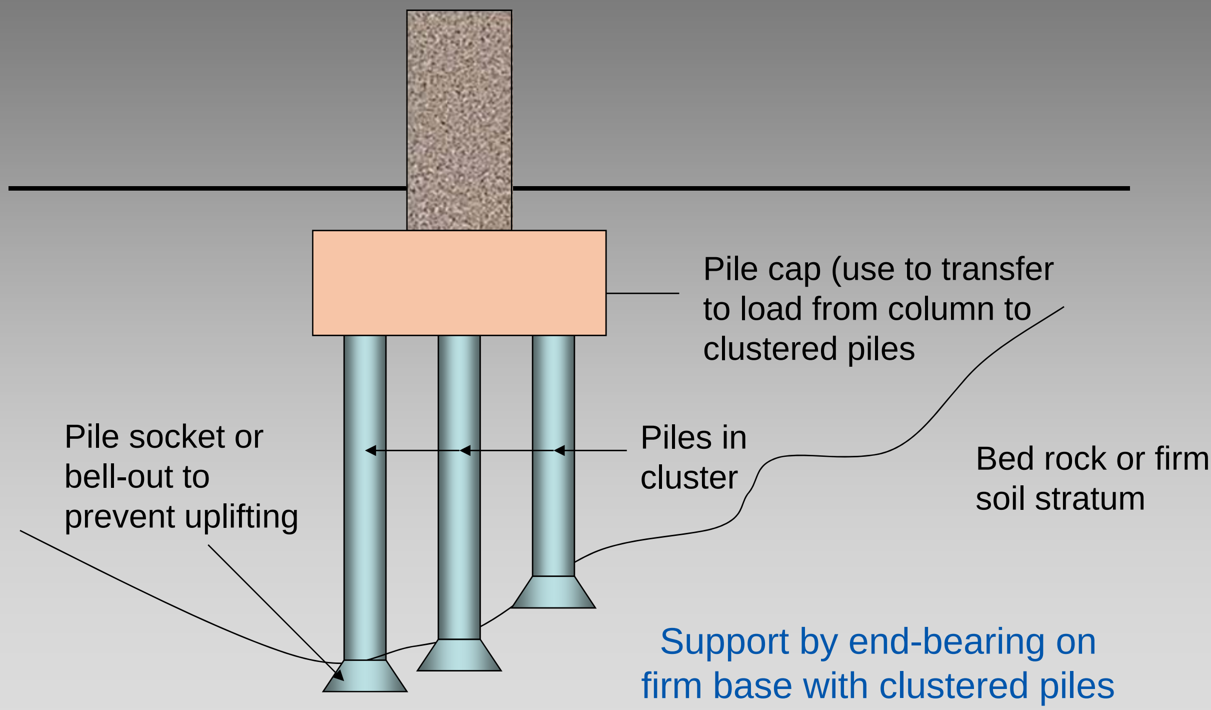
Load from a superstructure is transmitted to the subsoil either by:

- End-bearing – load is support by resting onto a firm stratum such as bed-rock or stratum of subsoil with the required bearing capacity.
- Skin friction – load is support by the frictional resistance so created between the contact surface of the pile and the embracing soil.

Loading Supports to Pile



Loading Supports to Pile



Support by end-bearing on firm base with clustered piles

Forming of a bell-out using a trimming cutter

Construction of Pile cap

Forming a pile cap for a clustered H-pile

Classification of Piled Foundation

Piled Foundation can be classified into:

1. End Bearing pile or Friction pile (or of combined nature)
2. Piles formed by manual or mechanical methods
3. Percussion Piles (driven by hammer) or Non-percussion Piles (form by augering, boring or drilling)
4. Displacement or replacement piles

Piles formed by manual methods (e.g. Hand-Dug Caisson)

Worker working inside the caisson shaft and to excavate using simple powered tools.

Piles formed by mechanical methods
(e.g. bored piles of various kinds)

Small dia. pile formed using boring rig and drill

Medium dia. pile formed using bucket barrel

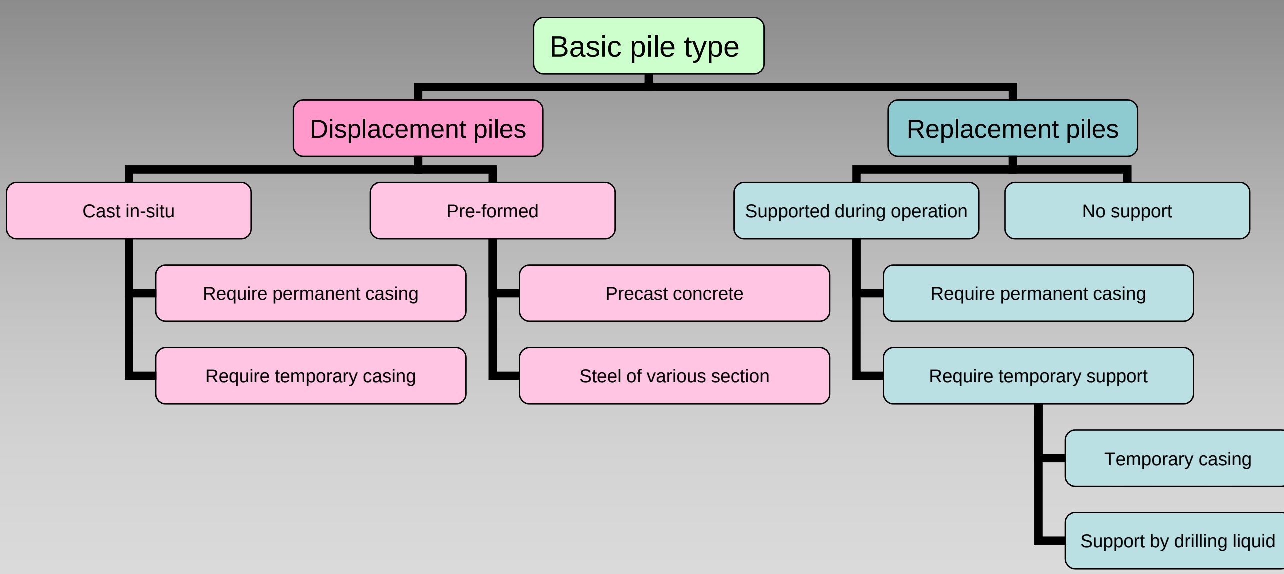
Large dia. Pile formed by reverse circulation drill

Piles formed by percussion methods

H-pile driven using gravity drop hammer

Precast circular-section pile driven by diesel hammer

Types of pile according to their operation

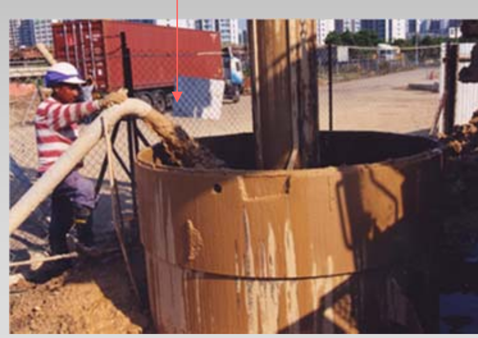


Operation of displacement pile

- Displacement piles
  - Cast in-situ (not common in HK)
    - Require permanent casing
    - Require temporary casing
  - Pre-formed
    - Precast concrete
    - Steel piles of various section

Operation of Replacement piles

- Replacement piles
  - Supported during operation
    - Require permanent casing (seldom use due to cost of the casing)
    - Require temporary support
      - Temporary casing
      - Support by drilling liquid
  - No support (seldom use due to high risk of Soil collapse during forming)



Foundation using steel H-pile

Steel H-pile – Standard universal sections are used as pile with the load taken up both by skin friction and end-bearing. The installation and equipment requirements are relatively simple, but the noise and vibration generated have restricted its use in urban areas. In case of boulders, pre-drilling can be carried out before the insertion of the pile. This method is economical and effective for taking load up to 3000 kN per pile.

Foundation using steel H-pile

Features of H-pile:

- Variety of standard pile sizes to fit different loading requirement
- Guaranteed integrity of pile
- Ease of handling & driving (12m long, about 2.5 tons per pile)
- Easy to connect piles by site welding
- Able to penetrate small boulders (certain deflection may occur)
- Allow for buckling if driven to greater depth

.

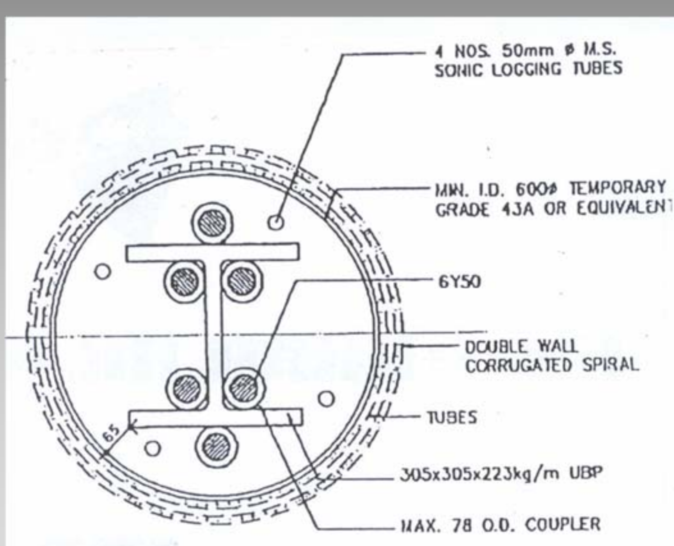
Foundation using steel H-pile

Inserting H-pile
after pre-boring

Hydraulic hammer
for driving pile

Site welding to connect
H-piles (12m per pile)

Foundation using rock socketed steel H-pile in pre-bored hole



Steel H-pile can be installed within a pre-bored holes formed in bedrock and grouted with cement or concrete to become a pile. This kind of pile is often sunk into bedrock and anchored the pile to produce an anti-lifting effect (tension pile). It can take load up to 3500 KN per pile. Due to the pre-boring action, it can easily penetrate through sub-soil with significant amount of boulders.

Rock socketed steel H-pile in pre-bored hole

Foundation using precast concrete pile

Precast concrete pile – Precast pile can be of square or circular in section, usually in modulated manner.

The Daido Pile is a typical example being used in Hong Kong. It is a pre-stressed hollow-section circular piles, 12m in length and in size between 400mm to 600mm. Pile sections are usually welded together using steel end plate.

Foundation using precast concrete pile

Features of Daido Pile:

- Hollow section to reduce weight (formed by spinning)
- Maximum allowable loads up to 3000 kN per pile
- Piles made of high strength concrete up to 75 MPa
- Easy to connect by welding the embedded steel end plate to lengthen pile to reach required depth
- Relatively reliable if handle and drive properly.

However, smoothness of the pile surface may reduce skin friction, as well as creating noise and vibration during driving.

Foundation using precast concrete pile

Coupling end plate to make pile connection easily by welding

Shoe to ease driving

Foundation using Mini-pile or Pipe Pile

Mini-pile or pipe-pile – By the use of compact drilling machines, steel pipes are inserted into the ground and grouted as pile.

By definition, a mini-pile is a pile consisting of a steel permanent casing with internal diameter not greater than 300mm, one or group of reinforcement bars in the middle are placed as load bearing element. The cavity in between will be filled with grout so that its rigidity can be improved. The core of the mini-ple will usually be socketed into rock to increase its ability to resist uplifting.

Foundation using Mini-pile

Features of this type of pile:

- Usual working load about 700 kN
- Piles are not designed for end bearing
- Convenient to be used in confined site with difficult access, limited working space or headroom.

Foundation using Mini-pile

- Drilling can be done easily in ground with large amount of boulders
- Drilling produces limited disturbance to neighbourhood (basically vibration free).
- Piles can be tensioned or socketed in sound rock and provide good resistance to overturning due to wind. (e.g. good to use as foundation to a tall lamp post)

Foundation using Mini-pile or Pipe Pile

Driving mini-pile using compact-size drilling rig in congested environment

Detail of the inserting bars and the grouted pile

Foundation using Mini-pile or Pipe Pile

Anchor plate at the pile head to connect the pile rigidly into the reinforced pile cap

Forming a pile cap with mini-piles

Foundation using bored piles

Principle of bored piles

Usually bored piles are of replacement nature, formed in-situ using a non-percussion approach.

The consideration when forming a bored piles involves 3 main factors:

1. How to form the bore (using what kind of machine and method to drill a hole in the ground)
2. How to protect the soil from collapsing into the bore hole during drilling (usually by inserting a steel casing or using a drilling fluid)
3. How to take the spoil out from the bore hole during drilling (by a grasp, drilling fluid, or compressor air)

Foundation using bored piles

Using small to medium sized in-situ concrete pile (Generally refers to piles ranging in size from 300mm to 900mm in diameter)

The use of drilling rigs of an appropriate capacity is required. Due to the possible collapse of subsoil during drilling, the forming process usually required temporary protection by the use of steel casings or some kind of drilling fluid such as bentonite slurry.

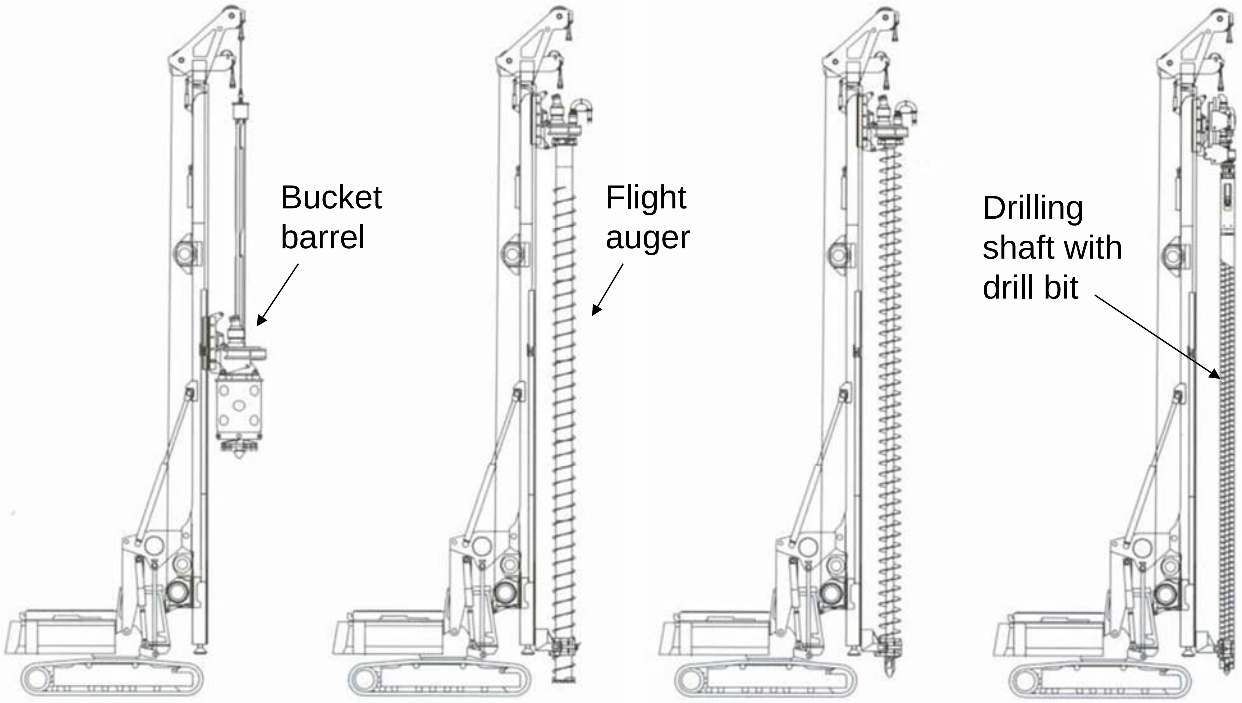
Due to the rapid development of a wide range of highly effective mechanical drilling equipment, this foundation method is becoming quite popular for the construction of medium to high-rise buildings in Hong Kong.

Steel casing

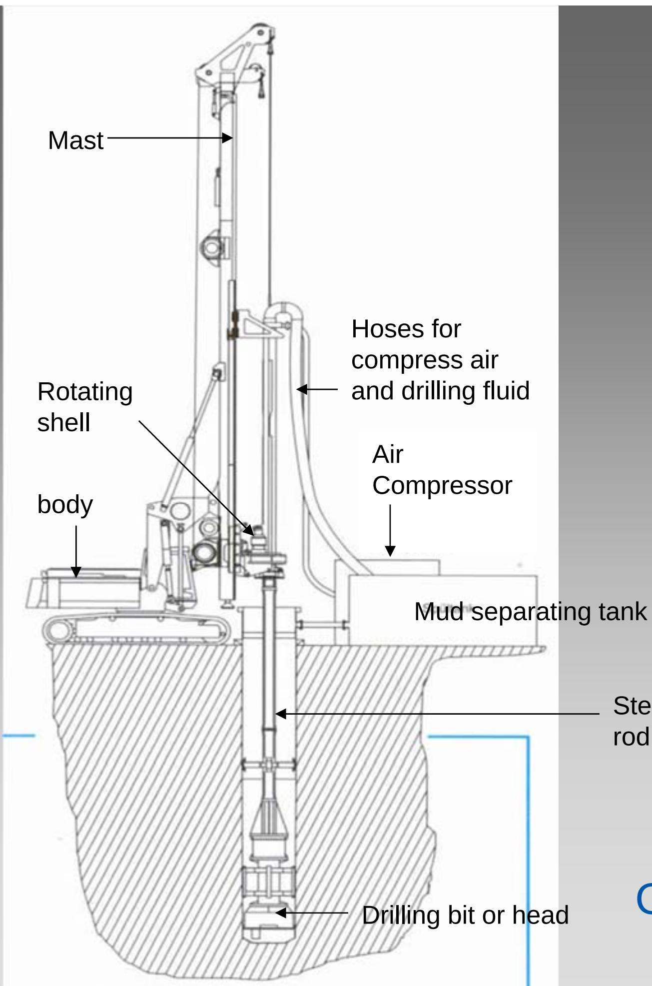
Helix auger

Various forms of drilling rig for pile max up to 900mm dia.

Drilling rig able to adopt to various boring arrangement



Various forms of the drilling rig for pile max up to 900mm dia.



Operation of the drilling rig

Rotating
shell

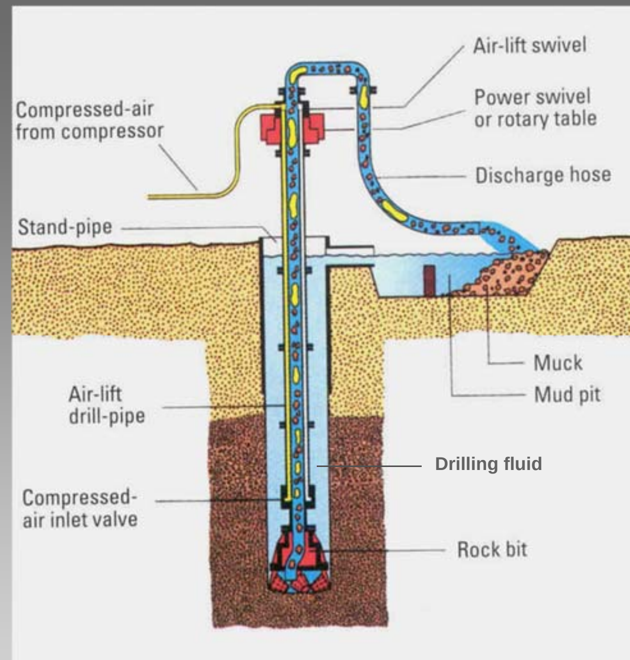
Drilling head for various
purposes – for soil (left)
and rock drilling (right)

Features of the drilling rig

Steel casing as temporary support during the boring process

purpose of the casing serves also as:

- drilling rod
- Soil protection
- Carrier tube to take the mud out from the bore hole using drilling fluid (bentonite)



Using of drilling fluid to remove mud from bore hole

Foundation using bored piles

Forming medium sized in-situ concrete pile using continuous flight auger (CFA) and bucket barrel

The using of CFA can form in-situ bored pile ranging from 500mm to 1200mm in diameter.

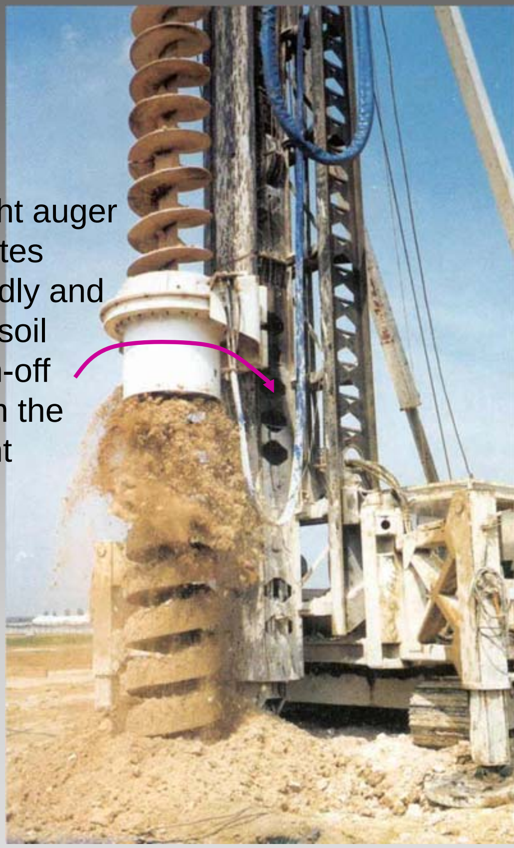
The use of CFA method requires a drilling rig with a rotating shell to drive modulated flight auger into soil to form a bore hole. Sometimes bentonite slurry is used in the boring process to prevent the hole from collapsing. A usual auger drill is used for boring in case of loose soil. While encounter boulder or decomposed rock, a auger head with cutting bit is used for the drilling

A section of flight auger

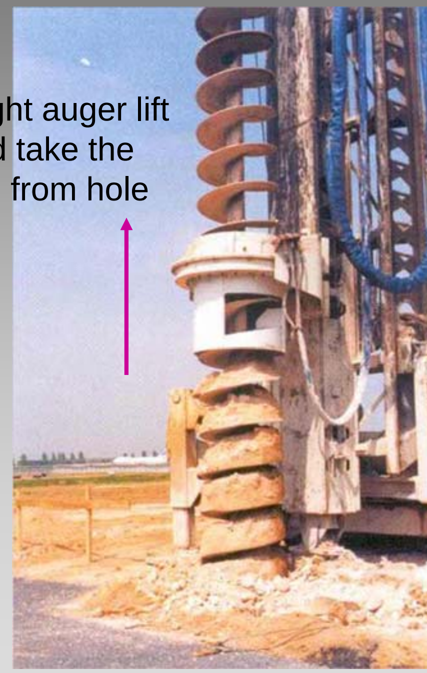
Using of Continuous Flight Auger to form a bore hole

Flight Auger Machine for larger diameter pile (up to 1.2m)

Soil taken out from the bore hole by the flight auger

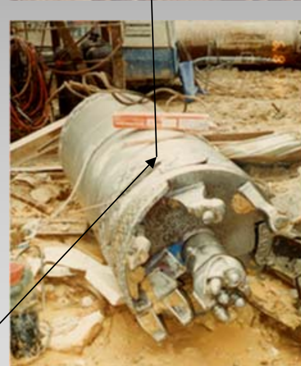


Flight auger rotates rapidly and the soil spin-off from the flight



Flight auger lift and take the soil from hole

Drilling rig to form a bore hole using bucket barrel



Bucket barrel of various sizes

Drilling rig to form a bore hole using bucket barrel

Bucket barrel taking soil from the borehole

Foundation using bored piles

Using Large diameter concrete bore pile – The boring process can be done manually or mechanically. In general, piles ranging in size from 1m to 3m diameter can be formed by mechanical methods while piles of 3m diameter and above are dug using manual methods.

Mechanical boring can be done by the use of grab-and-chisel or reverse circulation drilling, both of which require the use of a steel casing to stabilise the bore during excavation.

Sometimes, super large-sized piles of up to 6m to 8m diameter can be constructed. In this case, a cofferdam formed by sheet piles, soldier piles or in-situ concrete piles is provided for soil retaining purpose.

A 6.5m dia. caisson/ cofferdam for the insertion of a super-column (Cheung Kong Center)

Foundation using bored piles
(Manual-dug method – Caisson)

Hand-dug caisson is a very simple and low cost to form large-size bored pile due to the following reasons:

- No heavy equipment is required except powered tools
- Requires very little working space
- Can work for a number of piles at the same time
- Can work at very difficult condition such as steep slope
- Boulder inside the bore can be cut fairly easily by human worker

The only drawback is that it is very dangerous for worker working inside the caisson. Therefore, in 1998, the use of hand-dug caisson was banned due to the high accident rate. However, under special condition (e.g. work in steep slope), approval can still be obtained subject to the fulfilment of certain safety requirements.

Foundation using bored piles
(Manual-dug method – Caisson)

Working with hand-dug caisson in large site

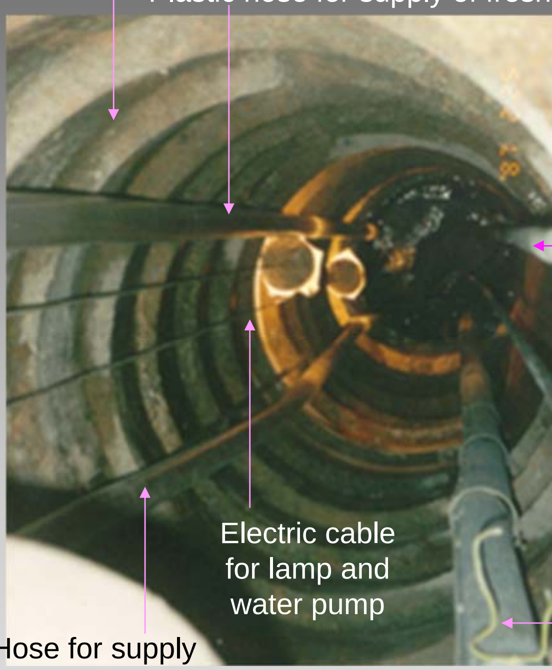
Working with hand-dug caisson in large site

Hand-dug caisson working in sloped site

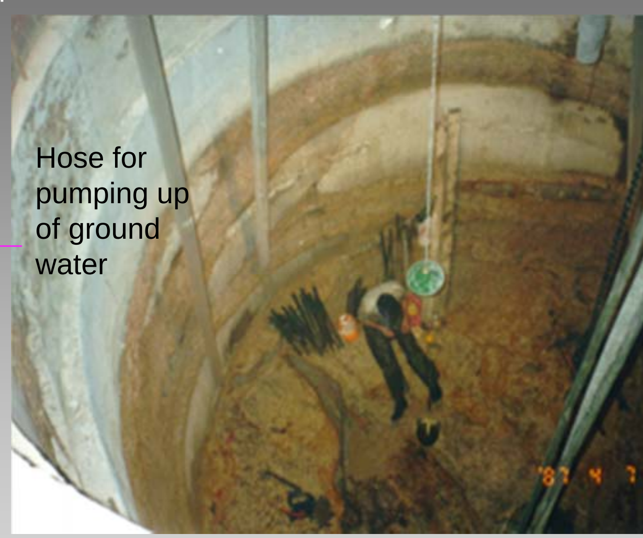
General set-up and operation of hand-dug caisson

Concrete ring to protect side of caisson from collapsing

Plastic hose for supply of fresh air



Hose for pumping up of ground water



Electric cable for lamp and water pump

Hose for supply of compress air for power tools

Tremie pipe for concreting

Working inside a caisson

Firmly secured gantry for the hoisting of excavated soil

Electrical hoisting block

Safe electrical supply

Fence with kicking plate

Firm stepping platform

Safety precaution for working with hand-dug caisson

Foundation using bored piles

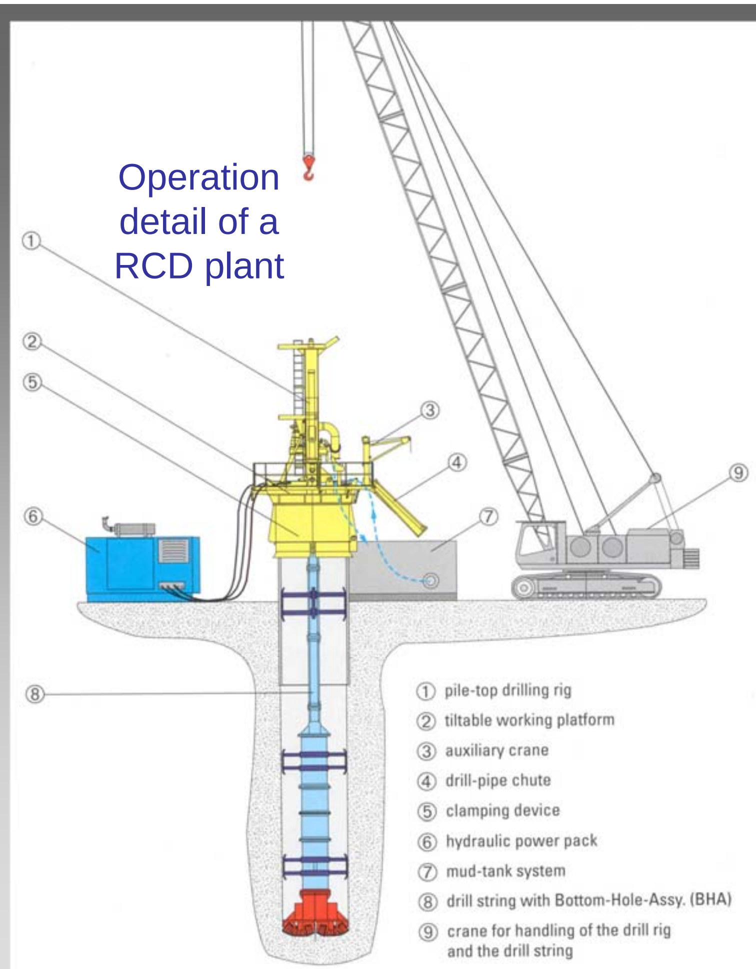
(formed by chisel and grab and support with casing)

Various forms of grab

Foundation using bored piles
(formed by chisel and grab and support with casing)

Various forms of chisel
(for rock breaking)

Bored pile formed by Reverse Circulation Drilling (RCD) method



Operation detail of a RCD plant

Rotator is used to grasp the casing, and make the tube:

1. Rotate to reduce frictional resistance between the tube and soil to make sinking or uplifting of the tube easier.
2. Hydraulic jack help tube sinks or lifts.

Rotator

Hydraulic jacks

Equipment to work with the steel casing – the rotator

Equipment to work with the steel casing – the oscillator

Hydraulic that make the casing oscillate

Oscillator – it works similar to the rotator but, instead of rotating the casing tube, it oscillates in a to-and-fro manner

Equipment to work with the steel casing – the oscillator

Hydraulic jacks for grasping and lifting the casing

Vibrator – a very heavy equipment sometimes use to help sinking the casing into the bore hole (mainly by gravity action)

Placing in of the casing tube

Overview of a Reverse Circulation Drill

The RCD seat firmly on top of the casing on the collar

The rotating shell for driving the drilling rod

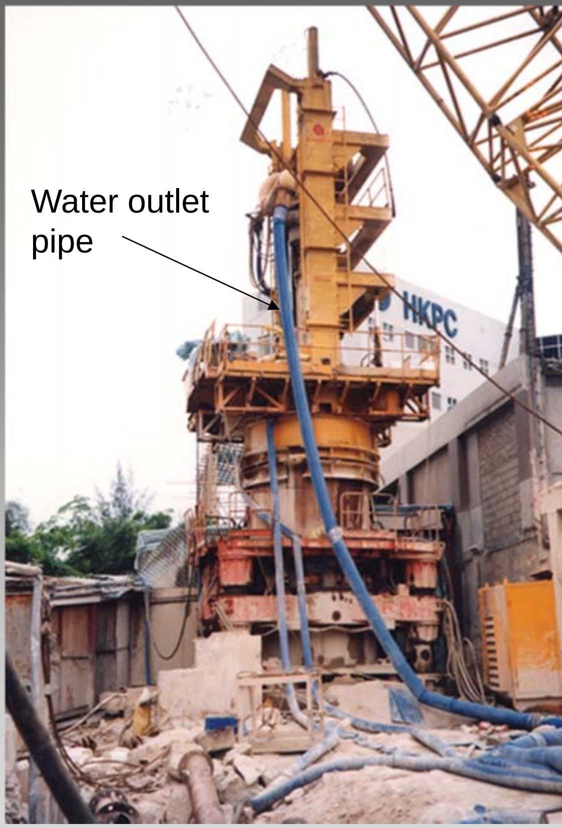
The Reverse Circulation Drilling Plant

The set-up – RCD rig, serving crane and spoil separating tank

Placing the drill rod into the bore hole with the RCD rig tilted to give way

Drilling rod and the auger head

The drilling process



Removal of spoil from the bore hole

Principle of spoil removal

1. The drilling rod with the auger head is used to form the bore.
2. The soil or debris rock is removed by the water that is pumped out from the bore
3. The circulating water carrying the spoil will have the soil and rock debris removed by a sedimentation tank
4. Water re-circulates back to the bore hole and repeated the spoil removal process

Examples of sedimentation tank for the removal of spoil

Forming bored-pile using drilling fluid

When piles (usually 600mm or above) are bored through unstable soil, the ground may be supported by the use of drilling fluid/mud. This fluid consists of bentonite (a kind of fine clay) suspension which restrains the particles of soil and form a membrane over the sides of the borehole. The membrane is kept in place by the hydrostatic pressure created by filling the hole with the fluid.

The first stage of the borehole is bored by rotary drill and lined with a temporary steel casing. This short length of casing prevents the collapse of loose surface soil and the overflowing of the drilling mud. On completion of this stage of boring, the hole is filled with bentonite slurry from the storage tanks.

Forming bored-pile using drilling fluid

The boring continues through the bentonite, which should be fed into the hole to the right level as boring proceeds in order to maintain the required counter pressure.

On reaching the required depth, reinforcement is lowered through the bentonite slurry and concrete is placed using a tremie pipe. The concrete displaces the mud, which is pumped back into the storage tank as it rises up the borehole. The short temporary casing is withdrawn as the concrete reaches the top of the hole

Placing reinforcement and concreting to bored pile

Reinforcement in the form of a steel cage for insertion into the bored hole before concreting

Placing reinforcement and concreting to bored pile

Placing reinforcement and concreting to bored pile

Testing of Piles

The following tests are required to determine the performance of piles:

1. Bearing capacity of pile
2. The integrity of pile (Integrity Test)
3. Settlement of pile under load (Loading Test)
4. Other tests including

CORE-DRILLING

SONIC ECHO TESTS

VIBRATION TEST

DYNAMIC LOAD TEST

TENSION TEST

LATERAL LOAD TEST

ULTRASONIC ECHO SOUNDER TEST

Testing of Piles

Bearing capacity of pile

Bearing capacity of pile depends on

1. Size, shape and type of pile
2. Property of soil embedding the pile

At a load greater than the bearing capacity of the pile, the soil embedding it will shows shear failure making the pile penetrate into the ground until it finds a depth that an equilibrium can be reached.

There is no perfect method to find the bearing capacity of a pile. Usually it is worked out using some kinds of empirical formula such as the Hilary Formula or Static Formula etc.

Testing of Piles

Integrity Test

The test is to find out the structural soundness of piles especially for those large-diameter concrete piles.

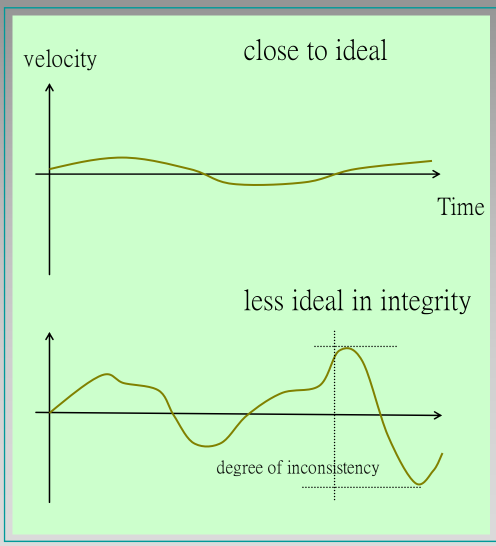
Example of structural soundness:

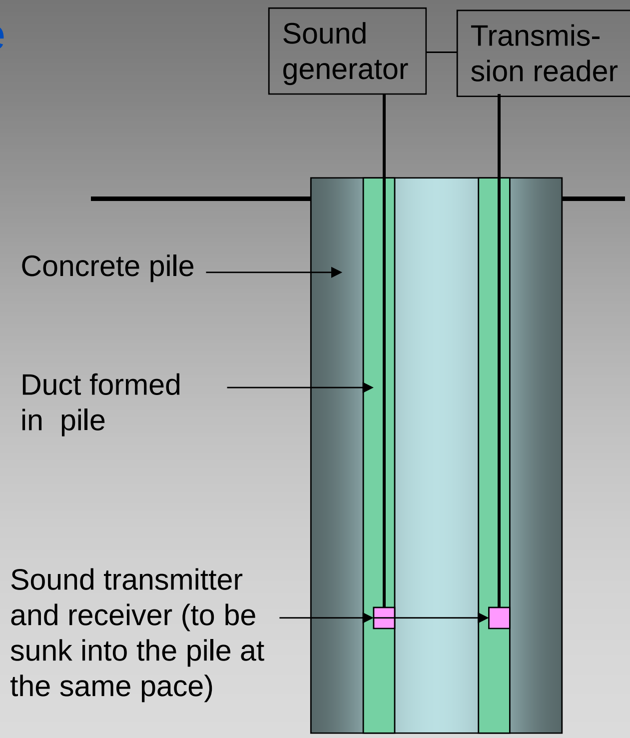
1. Whether there is any honeycomb in the pile
2. Compressive strength of the concrete in pile
3. Consistency of the concrete in pile

Examples of tests for testing Integrity of pile include the Sonic, Seismic, Echo or Vibration Test etc.

Testing of Piles

Testing Integrity of pile using Sonic Test





Testing of Piles

Workers setting up testing equipment on a temporary platform to carry out sonic test to a large-diameter bored pile

Testing of Piles

Loading Test

The test is to determine the settlement of a pile under load.

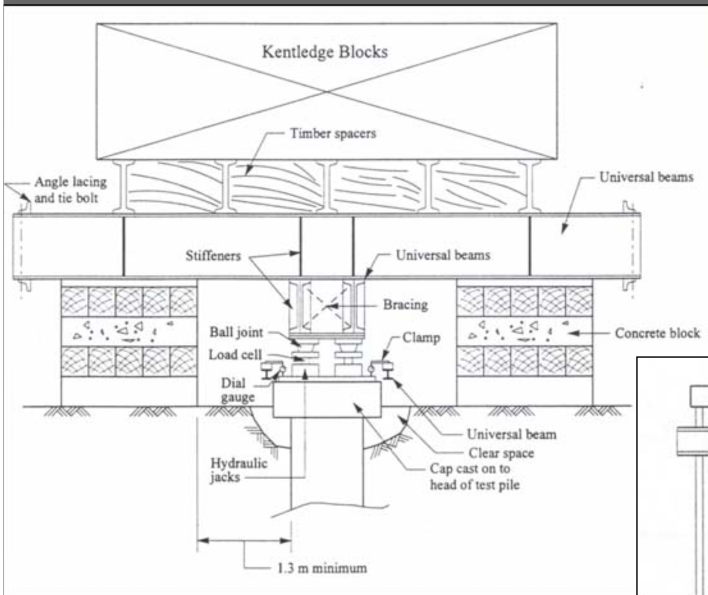
Equipment and set-up for the Loading Test include:

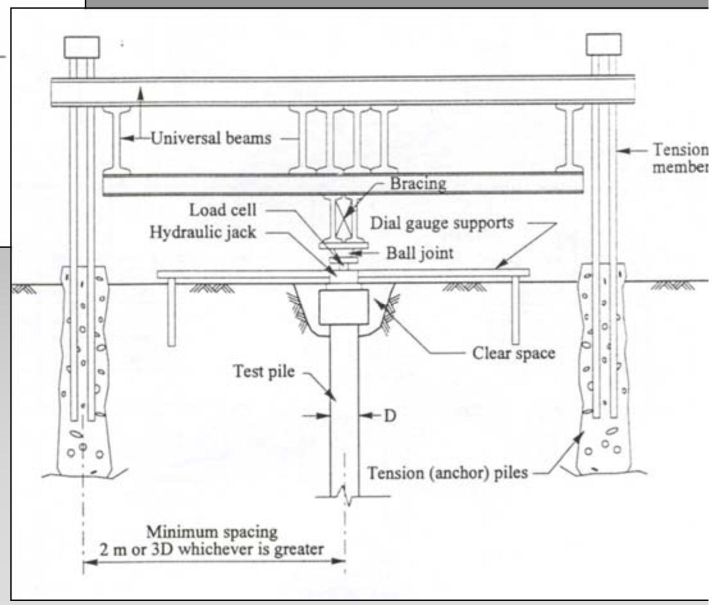
1. Kentledge or anchor piles to provide adequate reactions against applying the test loading
2. Deflectometers to measure the settlement
3. Reference frame for supporting the deflectometers and making measurement
4. Hydraulic loading equipment (jack)

Kentledge set-up for loading test –
purpose: to provide reaction against jacking

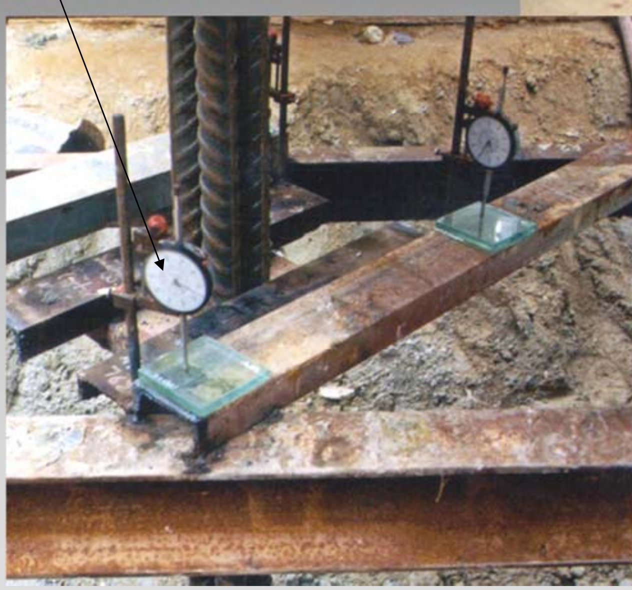
Loading test using anchor pile arrangement

Setting up of the reaction beam, hydraulic cylinder and deflection gauge

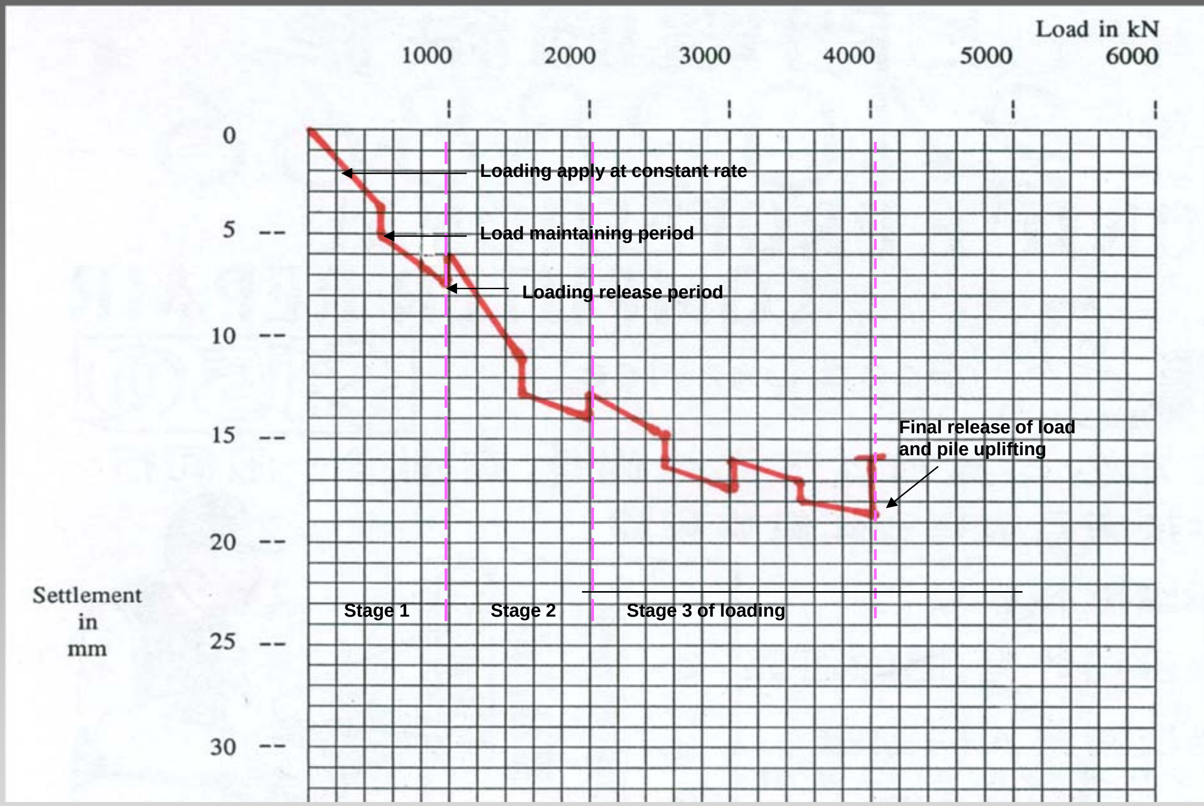




Set-up of Kentledge and Anchor Pile for Loading Test



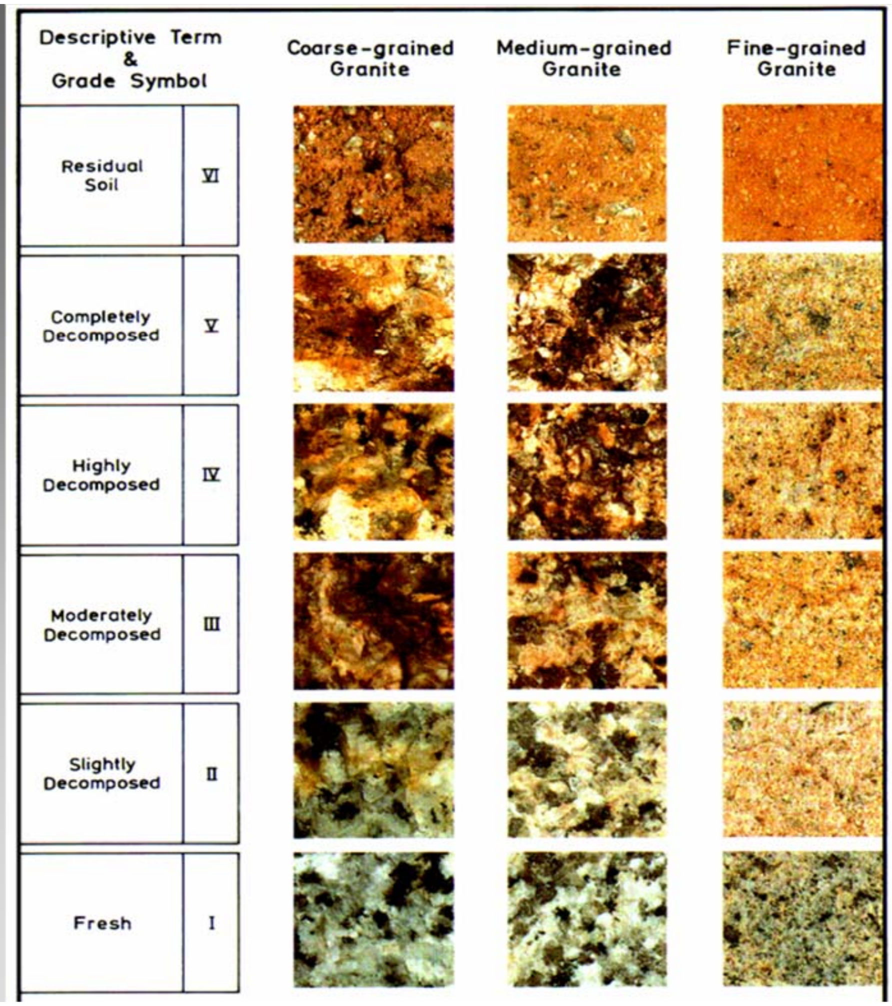
Jacking and measuring the settlement



Sample Settlement record –
pile to be tested in 3 stages with multiple loadings

Descriptive Term	Grade Symbol	General Characteristics for Granitic & Volcanic Rocks & Other Rocks of Equivalent Strength in the Fresh State
Residual Soil	VI	Original rock texture completely destroyed Can be crumbled by hand and finger pressure into constituent grains
Completely Decomposed	V	Original rock texture preserved Can be crumbled by hand and finger pressure into constituent grains Easily indented by point of geological pick Slakes when immersed in water Completely discoloured compared with fresh rock
Highly Decomposed	IV	Can be broken by hand into smaller pieces Makes a dull sound when struck by geological hammer Not easily indented by point of geological pick Does not slake when immersed in water Completely discoloured compared with fresh rock
Moderately Decomposed	III	Cannot usually be broken by hand; easily broken by geological hammer Makes a dull or slight ringing sound when struck by geological hammer Completely stained throughout
Slightly Decomposed	II	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer Fresh rock colours generally retained but stained near joint surfaces
Fresh	I	Not broken easily by geological hammer Makes a ringing sound when struck by geological hammer No visible signs of decomposition (i.e. no discolouration)

Classification of rock
(from Grade I to VI)



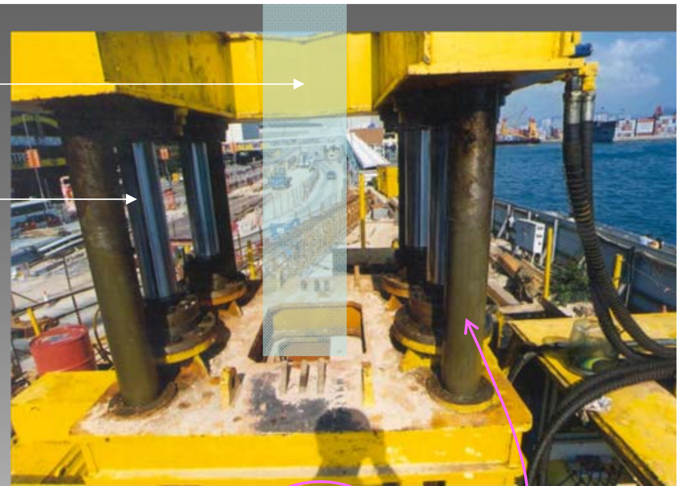
Rock samples

Other means to drive pre-formed piles by jacking

Precast concrete pile being pushed into the ground by a jacking platform

Position of pile

Hydraulic clamp for
jacking the pile



Another example of
jacking steel H-pile using
similar jacking platform

Gigantic machine
working in limited
headroom

Foundation working in extremely congested site

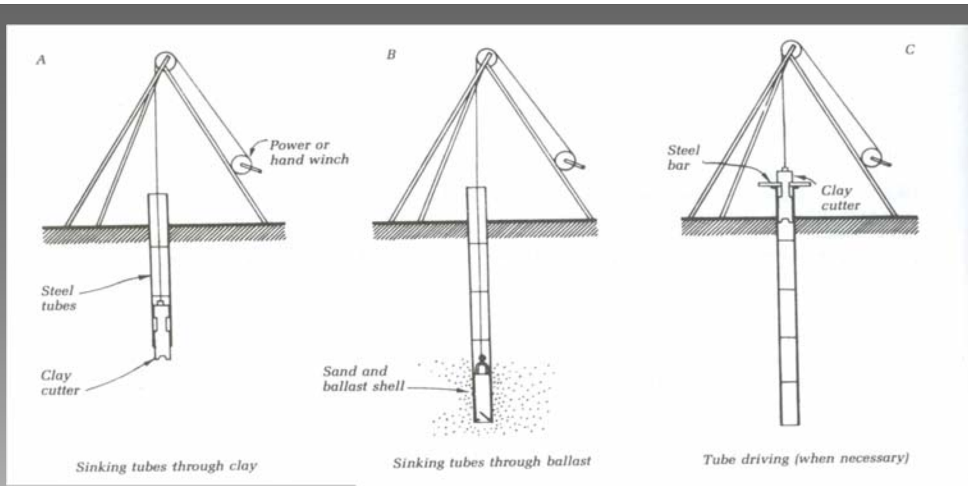
Characteristic and solution f congested site:

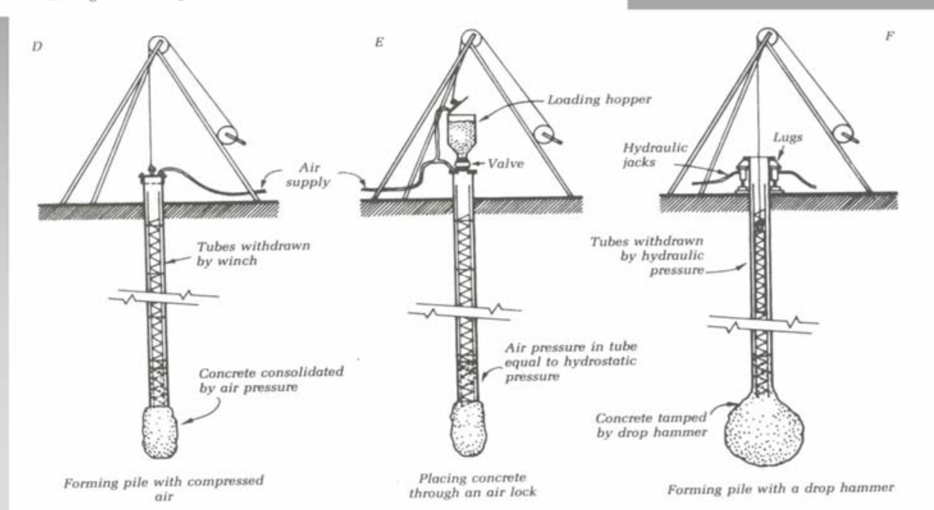
1. Usually with very limited working space and headroom
2. Only small and complex piling equipment can be employed
3. Pile used limited to small-sized option to avoid the using of large and heavy piling plant

Foundation working in extremely congested site –

using a kind of simple percussion in-situ bored pile

Operation principle of simple percussion bored pile



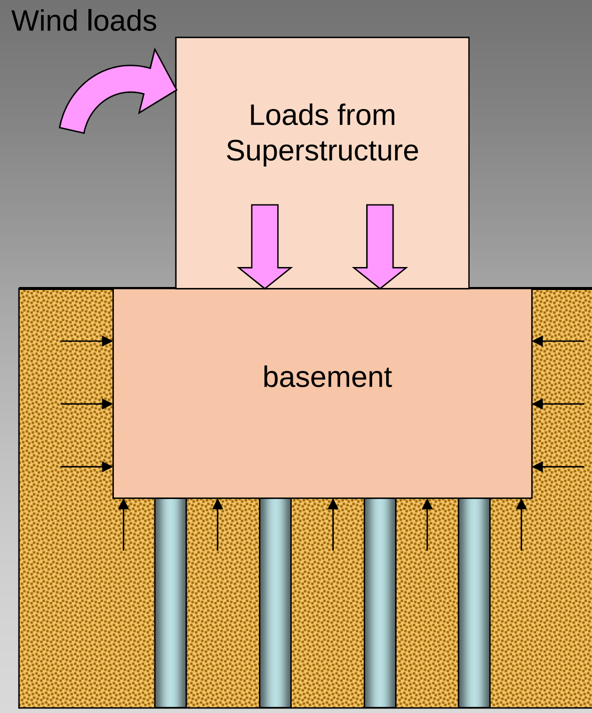


Foundation working in extremely congested site

Working along narrow & congested site along busy traffic roadway – using mini-piles

Basement as part of the Foundation

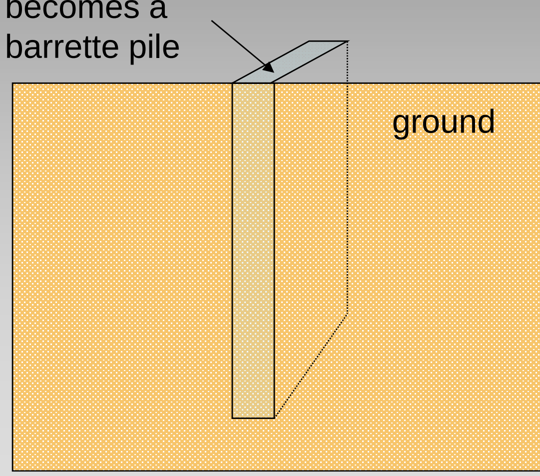
- Besides providing additional space below ground level for a building, loads from the superstructure are also transferred through the structure of a basement to the foundation.
- Such arrangement provides considerable rigidity to tall buildings base on the principle of buoyancy, that is, the basement box will displace the soil embedding it and balance the combined weight of the entire structure.



Overall buoyancy counteract part of the loads from upper structure

The cutters in the Hydrofraise form a rectangular trench in soil.

Rectangular trench formed in soil. After concreting, the trench becomes a barrette pile



Barrette formed by hydrofraise

Clamp shell (a soil cutting grasp) can also used to form a vertical trench in soil

Barrette formed by clamp shell

Other forms of Foundation

Steel columns rest on a 5m-thick raft on bedrock 18m below ground

Forming a cofferdam down to bedrock and construct a raft foundation without using piles – The Center project

Other forms of Foundation


Forming a cofferdam down to bedrock and construct a raft foundation without using piles – the IFC One project

Other forms of Foundation

A 72m dia. cofferdam side-supported by diaphragm wall

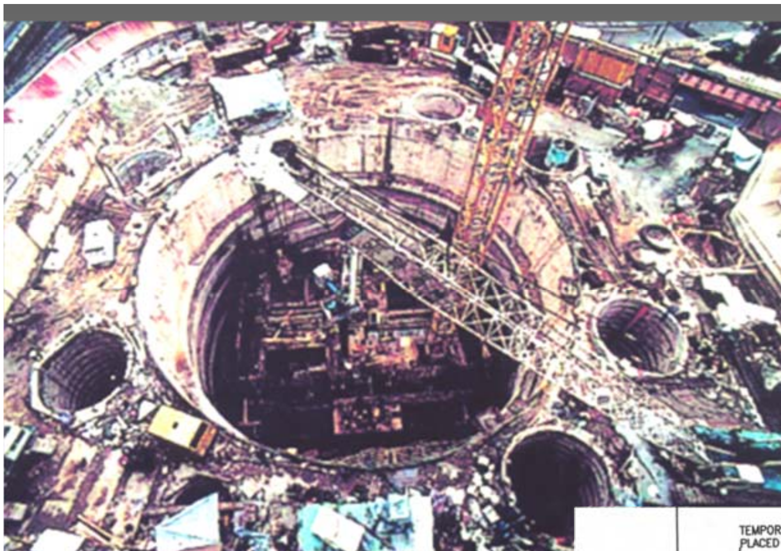
Forming a cofferdam down to bedrock and construct a raft foundation without using piles – the IFC Two project

Other forms of Foundation

Another similar cofferdam of size about 60m x 60m constructed for the Hotel block

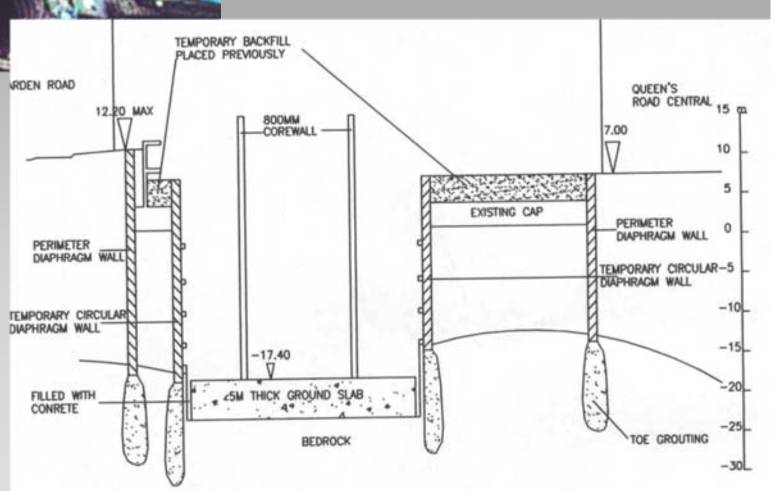
Tower block constructed over a 6.5m thick raft foundation

Forming a cofferdam down to bedrock and construct a raft foundation without using piles – the IFC Two project



Other forms of Foundation

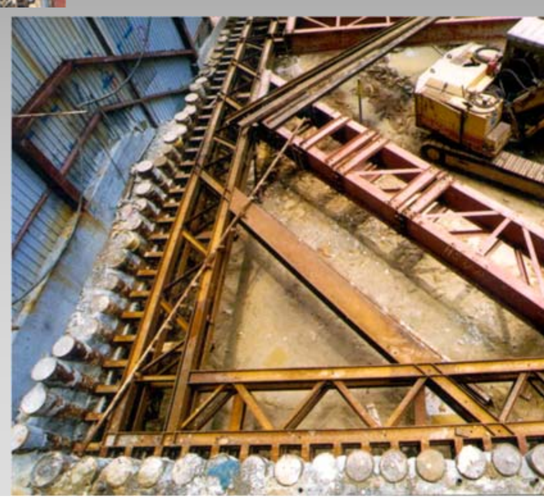
Further example - Cheung Kong Center project



Other uses of piles

Bored piles as excavation support

Mini-piles used as excavation support



Other uses of piles – underpinning work

Underpinning for a highway bridge – the Tuen Mun Highway at Tsuen Wan being cut across by the West Rail Tai Lam Tunnel

Other uses of piles Underpinning for a highway bridge

Other uses of piles

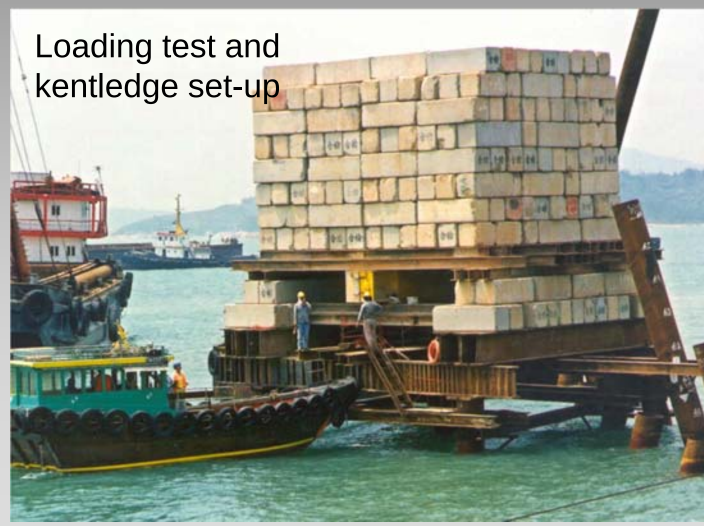
Piles used as marine piers to support the deck for the Container Terminal No.8 and 9

Other uses of piles

Piles for marine facilities

Other uses of piles

Driving steel tube (reinforced and grouted afterward) as piers for support deck structure



Loading test and kentledge set-up

Temporary platform and equipment set-up to facilitate the construction of the Terminal deck

Container Terminal No.9 in Tsing Yi

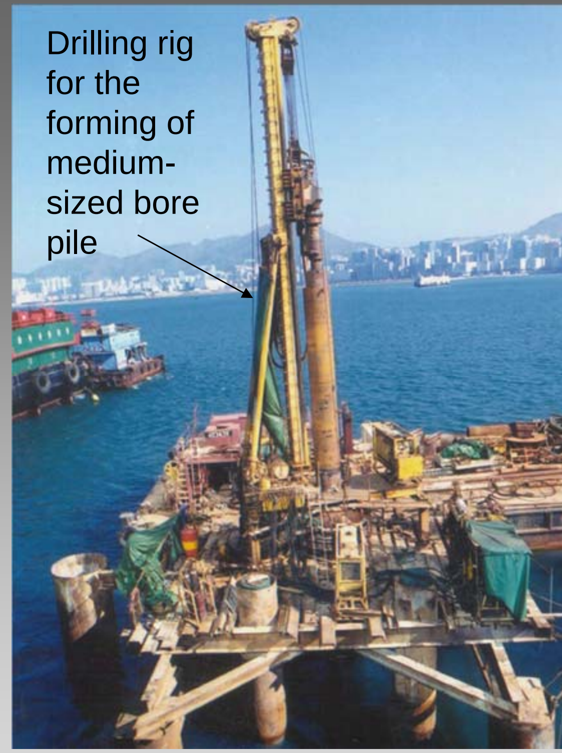
Cleansing of the bore before concreting

Pipe washer

Container Terminal No.9 in Tsing Yi

Casting the deck on the marine piers

Container Terminal No.9 in Tsing Yi



Marine piling for Quarry Bay Traffic Improvement Works

Forming the pile cap on top of the piles

Marine piling for Quarry Bay Traffic Improvement Works

Forming bore-pile wall using RCD
for the Wanchai-Central Bypass

Reference:

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The end of presentation