Types of foundation

- Shallow foundations
- Deep foundations

Shallow foundations (sometimes called 'spread footings') include pads ('isolated footings'), strip footings and rafts.
Deep foundations include piles, pile walls, diaphragm walls and caissons.

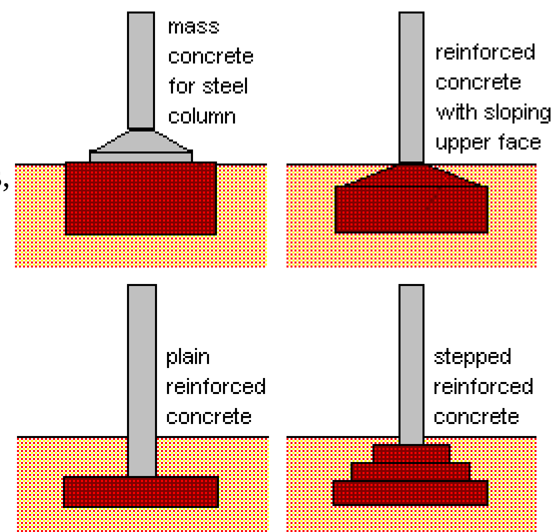
Shallow foundations

- Pad foundations
- Strip foundations
- Raft foundations

Shallow foundations are those founded near to the finished ground surface; generally where the founding depth (D_f) is less than the width of the footing and less than 3m. These are not strict rules, but merely guidelines: basically, if surface loading or other surface conditions will affect the bearing capacity of a foundation it is 'shallow'. Shallow foundations (sometimes called 'spread footings') include pads ('isolated footings'), strip footings and rafts.
Shallows foundations are used when surface soils are sufficiently strong and stiff to support the imposed loads; they are generally unsuitable in weak or highly compressible soils, such as poorly-compacted fill, peat, recent lacustrine and alluvial deposits, etc.

Pad foundations

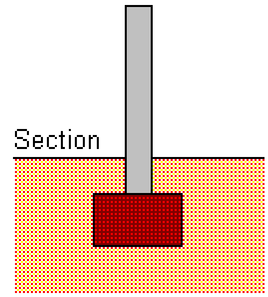
Pad foundations are used to support an individual point load such as that due to a structural column. They may be circular, square or reactangular. They usually consist of a block or slab of uniform thickness, but they may be stepped or haunched if they are required to spread the load from a heavy column. Pad foundations are usually shallow, but deep pad foundations can also be used.

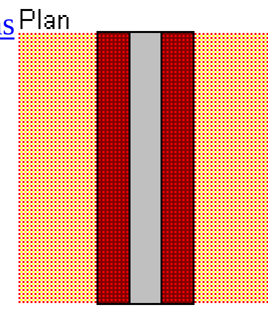


[Shallow foundations]

Strip foundations

Strip foundations are used to support a line of loads, either due to a load-bearing wall, or if a line of columns need supporting where column positions are so close that individual pad foundations would be inappropriate.





Shallow foundations

Raft foundations

Raft foundations are used to spread the load from a structure over a large area, normally the entire area of the structure. They are used when column loads or other structural loads are close together and individual pad foundations would interact.

A raft foundation normally consists of a concrete slab which extends over the entire loaded area. It may be stiffened by ribs or beams incorporated into the foundation.

Raft foundations have the advantage of reducing differential settlements as the concrete slab resists differential movements between loading positions. They are often needed on soft or loose soils with low bearing capacity as they can spread the loads over a larger area.

Types of foundation

Deep foundations

- Piles

Deep foundations are those founding too deeply below the finished ground surface for their base bearing capacity to be affected by surface conditions, this is usually at depths >3 m below finished ground level. They include piles, piers and caissons or compensated foundations using deep basements and also deep pad or strip foundations. Deep foundations can be used to transfer the loading to a deeper, more competent strata at depth if unsuitable soils are present near the surface.

Piles are relatively long, slender members that transmit foundation loads through soil strata of low bearing capacity to deeper soil or rock strata having a high bearing capacity. They are used when for economic, constructional or soil condition considerations it is desirable to transmit loads to strata beyond the practical reach of shallow foundations. In addition to supporting structures, piles are also used to anchor structures against uplift forces and to assist structures in resisting lateral and overturning forces.

Piers are foundations for carrying a heavy structural load which is constructed insitu in a deep excavation.

Caissons are a form of deep foundation which are constructed above ground level, then sunk to the required level by excavating or dredging material from within the caisson.

Compensated foundations are deep foundations in which the relief of stress due to excavation is approximately balanced by the applied stress due to the foundation. The net stress applied is therefore very small. A compensated foundation normally comprises a deep basement.

Deep foundations

Piles

- Types of pile
- Types of construction
- Factors influencing choice
- Pile groups

Piled foundations can be classified according to
the type of pile
(different structures to be supported, and different ground conditions, require different types of resistance) and
the type of construction
(different materials, structures and processes can be used).

Piles

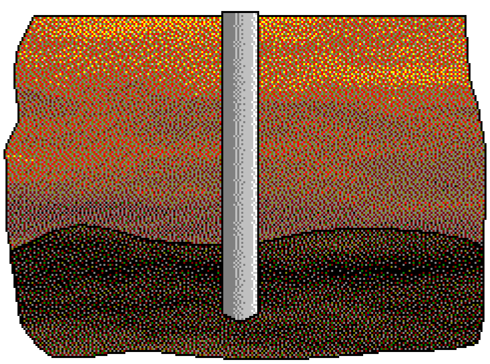
Types of pile

- End bearing piles
- Friction piles
- Settlement reducing piles
- Tension piles
- Laterally loaded piles
- Piles in fill

Piles are often used because adequate bearing capacity can not be found at shallow enough depths to support the structural loads. It is important to understand that piles get support from both **end bearing** and **skin friction**. The proportion of carrying capacity generated by either end bearing or skin friction depends on the soil conditions. Piles can be used to support various different types of structural loads.

Types of pile

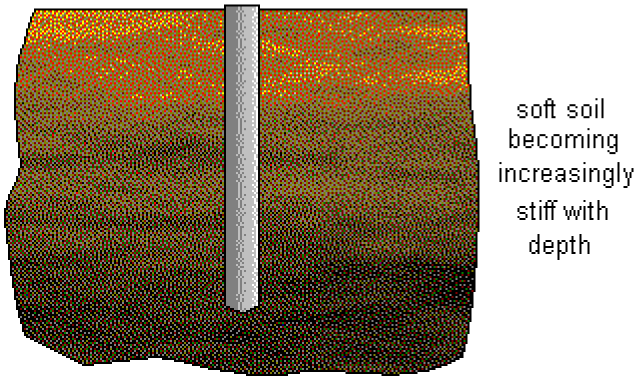
End bearing piles



End bearing piles are those which terminate in hard, relatively impenetrable material such as rock or very dense sand and gravel. They derive most of their carrying capacity from the resistance of the stratum at the toe of the pile.

Types of pile

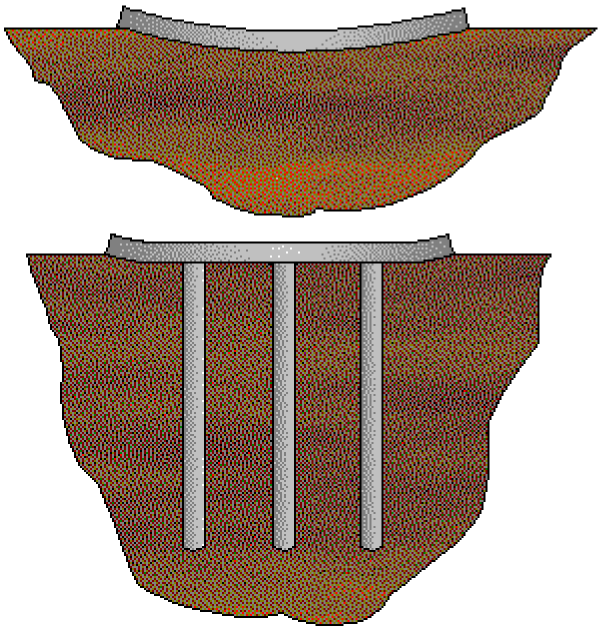
Friction piles



Friction piles obtain a greater part of their carrying capacity by skin friction or adhesion. This tends to occur when piles do not reach an impenetrable stratum but are driven for some distance into a penetrable soil. Their carrying capacity is derived partly from end bearing and partly from skin friction between the embedded surface of the soil and the surrounding soil.

Types of pile

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.

Types of pile

Tension piles

Structures such as tall chimneys, transmission towers and jetties can be subject to large overturning moments and so piles are often used to resist the resulting uplift forces at the foundations. In such cases the resulting forces are transmitted to the soil along the embedded length of the pile. The resisting force can be increased in the case of bored piles by under-reaming. In the design of tension piles the effect of radial contraction of the pile must be taken into account as this can cause about a 10% - 20% reduction in shaft resistance.

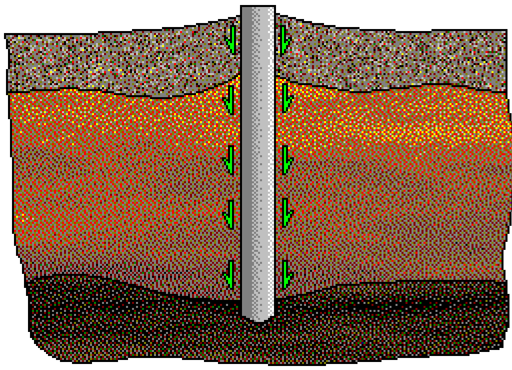
Types of pile

Laterally loaded piles

Almost all piled foundations are subjected to at least some degree of horizontal loading. The magnitude of the loads in relation to the applied vertical axial loading will generally be small and no additional design calculations will normally be necessary. However, in the case of wharves and jetties carrying the impact forces of berthing ships, piled foundations to bridge piers, trestles to overhead cranes, tall chimneys and retaining walls, the horizontal component is relatively large and may prove critical in design. Traditionally piles have been installed at an angle to the vertical in such cases, providing sufficient horizontal resistance by virtue of the component of axial capacity of the pile which acts horizontally. However the capacity of a vertical pile to resist loads applied normally to the axis, although significantly smaller than the axial capacity of that pile, may be sufficient to avoid the need for such 'raking' or 'battered' piles which are more expensive to install. When designing piles to take lateral forces it is therefore important to take this into account.

Types of pile

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.

Piles

Types of pile construction

- Displacement piles
- Non-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. 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.

Types of pile construction

Displacement piles

- Totally preformed displacement piles
- Driven and cast-in-place displacement piles
- 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.

Displacement piles

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.

Displacement piles

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.

Displacement piles

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.

Displacement piles

Methods of installation

- Dropping weight
- Diesel hammer
- Vibratory methods of pile driving
- Jacking methods of insertion

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

Methods of installation

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.

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.

Methods of installation

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.

[Methods of installation]

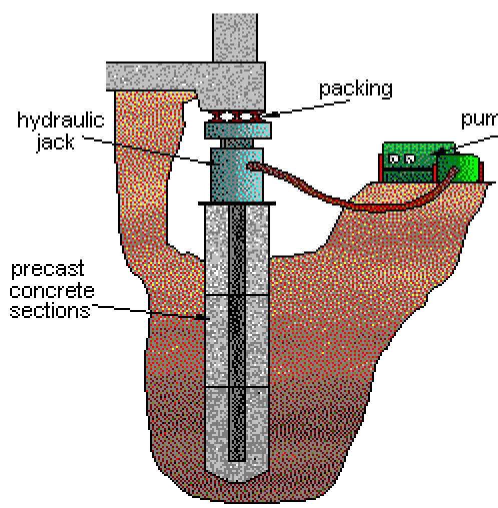
Vibratory methods of pile driving

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.

[Methods of installation]

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.



[Types of pile construction]

Non-displacement piles

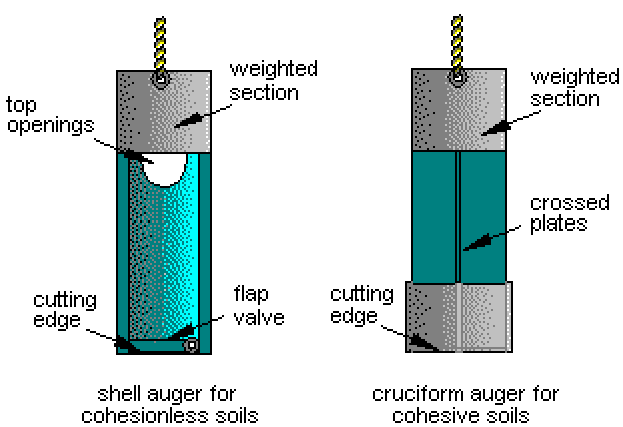
- Small diameter bored cast-in-place piles
- Large diameter bored cast-in-place piles
- Partially preformed piles
- Grout or concrete intruded piles

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. 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. When boring through more unstable ground, such as gravels, some form of casing or support, such as a bentonite slurry, may be required. 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.

This method of construction produces an irregular interface between the pile shaft and surrounding soil which affords good skin frictional resistance under subsequent loading.

[Non-displacement piles]

Small diameter bored cast-in-place piles



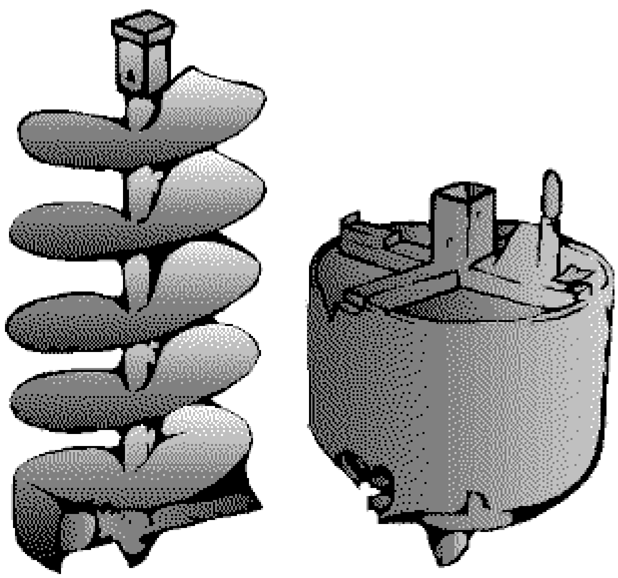
These tend to be 600mm or less in diameter and are usually constructed by using a tripod rig. The equipment consists of a tripod, a winch and a cable operating a variety of tools. The basic tools are shown in this diagram.

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.

[Non-displacement piles]

Large diameter bored cast-in-place piles



short flight clay auger   drilling bucket

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.

Non-displacement piles

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.

Non-displacement piles

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.

Piles

Factors influencing choice of pile

- Location and type of structure
- Ground conditions
- Durability
- Cost

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.

Location and type of structure

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. On land the choice is not so straight forward. 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. For heavy structures exerting large foundation loads, large-diameter bored piles are usually the most economical. 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.

· Single pile failure
· Failure of rows of piles
· Block failure

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.