

7 FOUNDATIONS

Foundations transmit loads to the ground. They do that through the bearing surface. These loads can be dead, impose and wind loads mainly, but we can have other efforts, such as earthquake or rheological behaviour. They must do that in a manner so not to cause any settlement which would impair the stability or cause damage to any part of the building.

Foundations can be made with materials which support compression and tensile stress. Stone blocks were used before, sometimes joined with any kind of binder (lime or hydraulic lime). At present the most common is the use of reinforced concrete, although occasionally it is also developed with precast elements. Timber is not a common element for foundations due to durability, but there are some piling foundations with this material.

In general, reinforced concrete foundations can be classified in shallow and deep foundations. Most shallow types are constructed within 2.0 m of the ground level. Foundations which need to be taken below 5 m deep are considered as deep ones.

Settlements are due to the fail of the soil below the foundation. Sometimes, this settlement is under control (we know it is going to happen and calculate the foundation according to it), other times it is not controlled (unpredictable). We can also have an equal or differential settlement below the foundation surface. The second one is much more dangerous to the stability of the structure.

We must have a geotechnical study to know the bearing capacity of every layer in the ground. According to it, we can establish which the bearing layer is going to be and the depth of this foundation. The foundation must always be embedded the bearing layer. The topsoil is not good for bearing, so it must be eliminated (minimum 300 mm).

7.1 Shallow foundations

Shallow foundations are not developed more than 5 metres deep. Earthworks do not need special equipment to be carried out.

According to the shape and way of load transmission to the ground, we can have different kinds of shallow foundations.

- Pad foundations
- Strip foundations
- Raft foundations

7.1.1 Pad foundations

It is built with concrete dices of squared surface. The upper surface can be flat or pyramidal. Thickness is enough to be able to support shear force, and the steel reinforcement is usually located at the bottom with rebars in both directions. The objective of this reinforcement is to absorb the tension efforts in the below surface.

This foundation is suitable for most subsoils except loose sands and gravels.

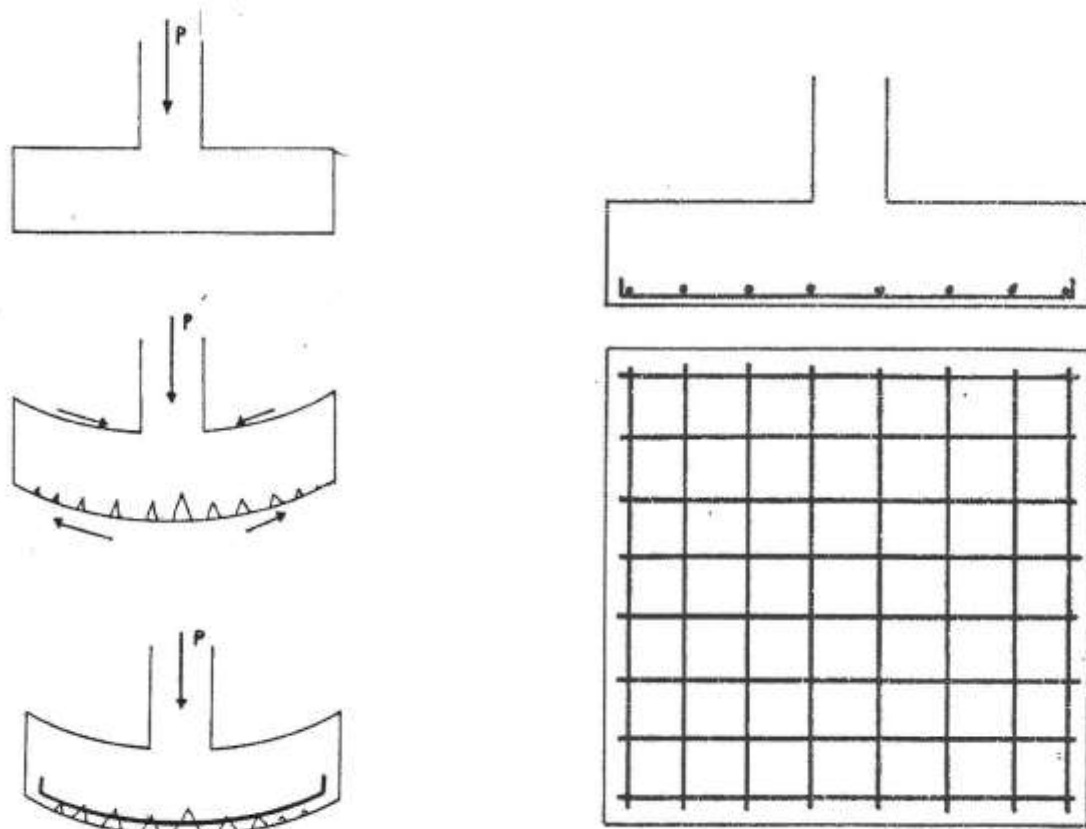


Figure 1. (Construction Technology notes, University of Alicante – Spain)

We can have axial loads, bending moments and shear forces, and a lot of combinations with them. The main situations are like this:

- If the loads are concentrated in the middle and there are not any bending moments (the previous case), the distribution of loads in the foundation base is balanced.
- If we introduce an eccentricity (E) in the loads and/or bending moments, the distribution of loads is not balanced.

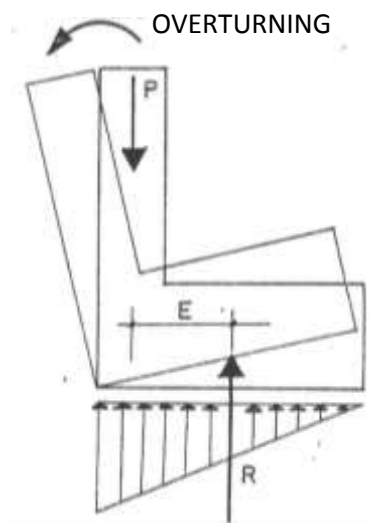


Figure 2. (Construction Technology notes, University of Alicante – Spain).

We have situation b when we have eccentric columns, for instance. In these situations, we can join with tie beams. In these beams, we have sagging and hogging moments giving rise to top and bottom reinforcement in the various locations.

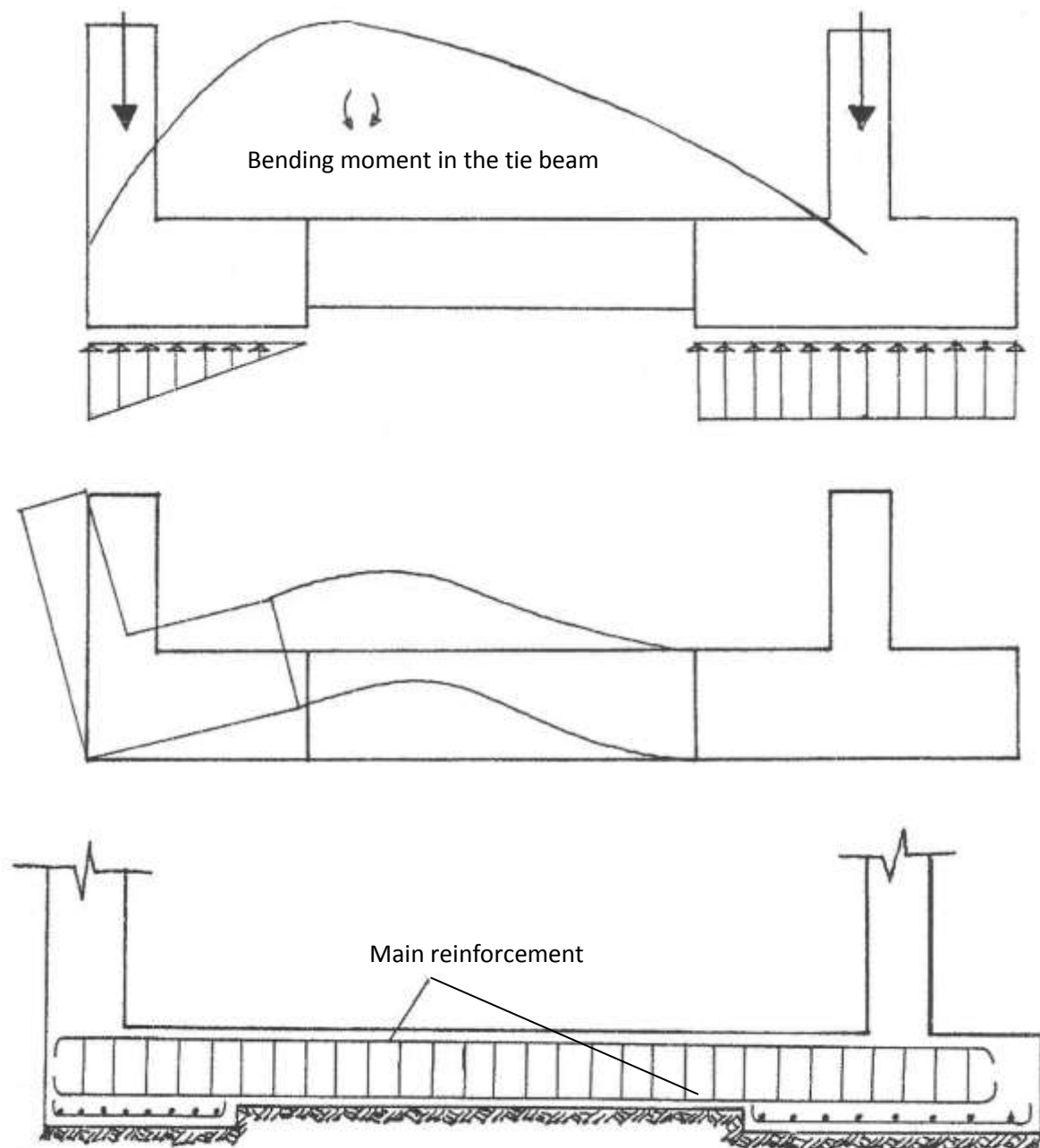


Figure 3. (Construction Technology notes, University of Alicante – Spain).

A good solution is also to consider a combined foundation. This consists of a reinforced concrete slab placed at right angles to the line of columns to link together. The reinforcement will be at the same locations as the tie beam.

Alternative column foundation is the cantilever foundation. These foundations are usually specified when it is necessary to ensure that no pressure is imposed on an existing substructure. This

cantilever beam sometimes acts about a short fulcrum column positioned near to the existing structure, and other times the beam cantilevers beyond a slab base.

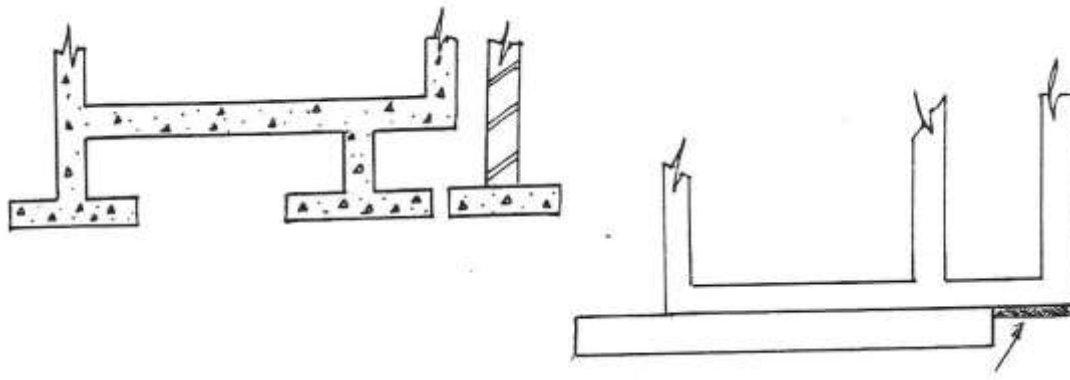


Figure 4. (John Greville's notes, UWTSD).

About shear force, we must think about the load P , which is concentrated, and the foundation must distribute this load over the bearing ground surface. That is why shear force is important inside. It can be absorbed in two ways:

- Increasing the concrete section
- Introducing shear force reinforcement

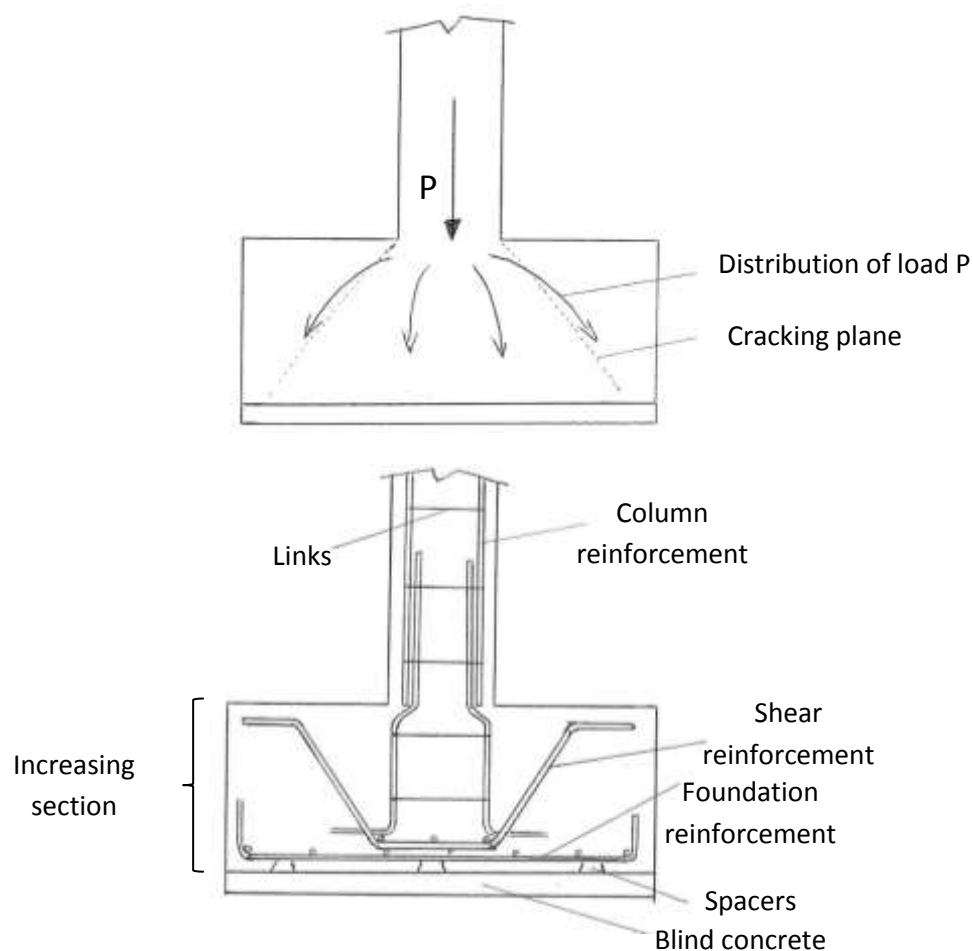


Figure 5. (Ferriz Papi, 2015).

Sometimes, two columns are very close and the bearing capacity of the soil is affected due to their proximity. In this case, the best solution is to combine them and join in one unique pad foundation.

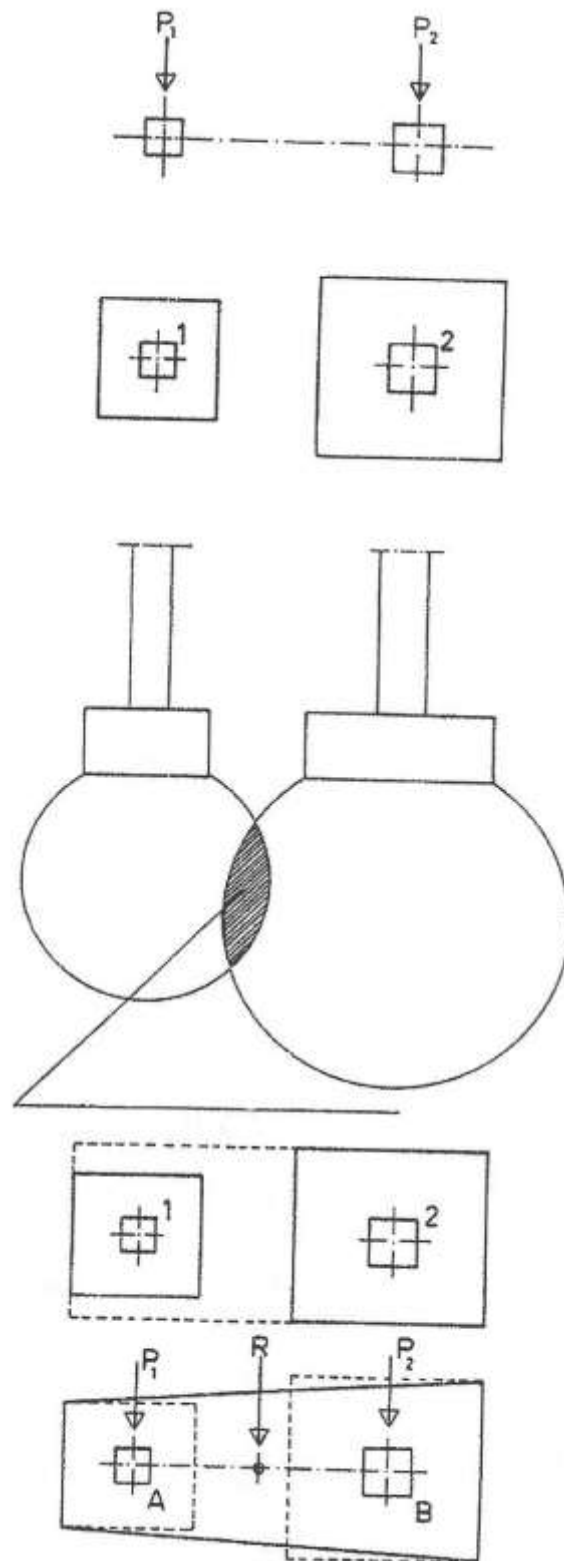
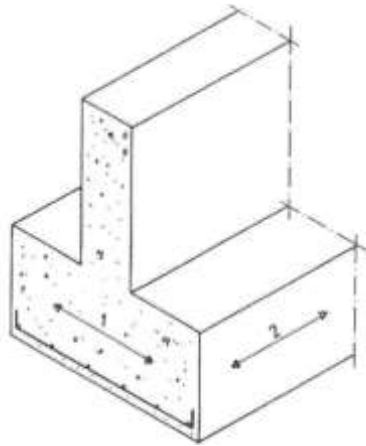


Figure 6. (Construction Technology notes, University of Alicante – Spain).

7.1.2 Strip foundations

This kind of foundation is suitable for most sub-soils and light structural loadings such as those encountered in low to medium rise domestic dwelling where mass concrete can be used. They may also be used for lightly bonded, closely spaced columns. This foundation is the typical solution for retaining walls. They transmit shorter loads to the soil as the bearing surface is bigger.

Strip foundations can support walls or columns. In the first case, the main reinforcement will be perpendicular to the wall. The parallel reinforcement (secondary) will be only useful to distribute loads.



1. Main reinforcement
2. Secondary reinforcement (for distribution of loads)

Figure 7. (Construction Technology notes, University of Alicante – Spain).

In the case of columns, it is important to understand the deformation there are in this foundation with the application of loads in each column. This will help to know which zones need to be improved with reinforcement.

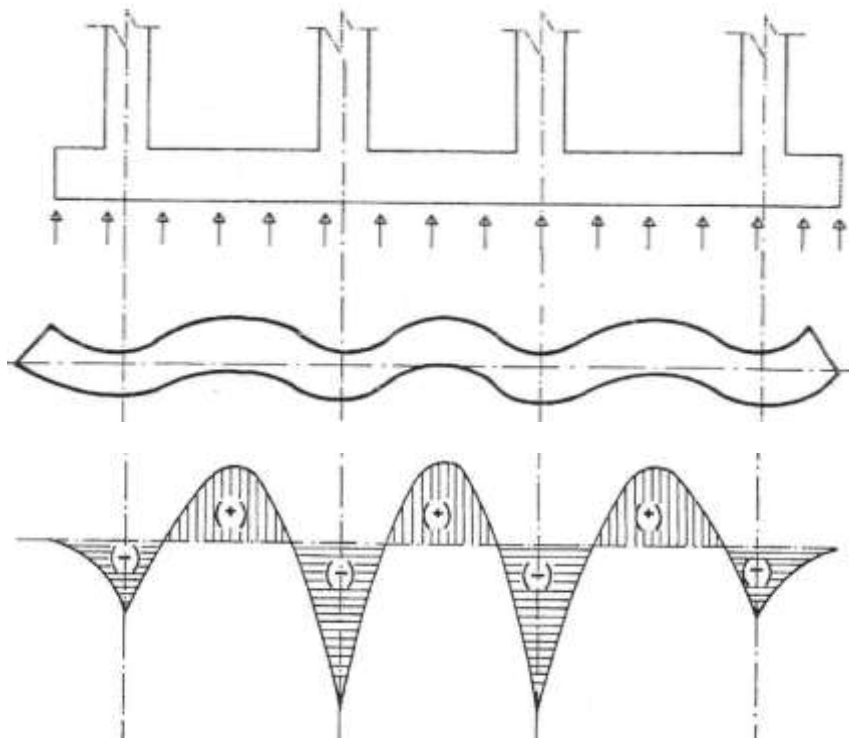


Figure 8. (Construction Technology notes, University of Alicante – Spain).

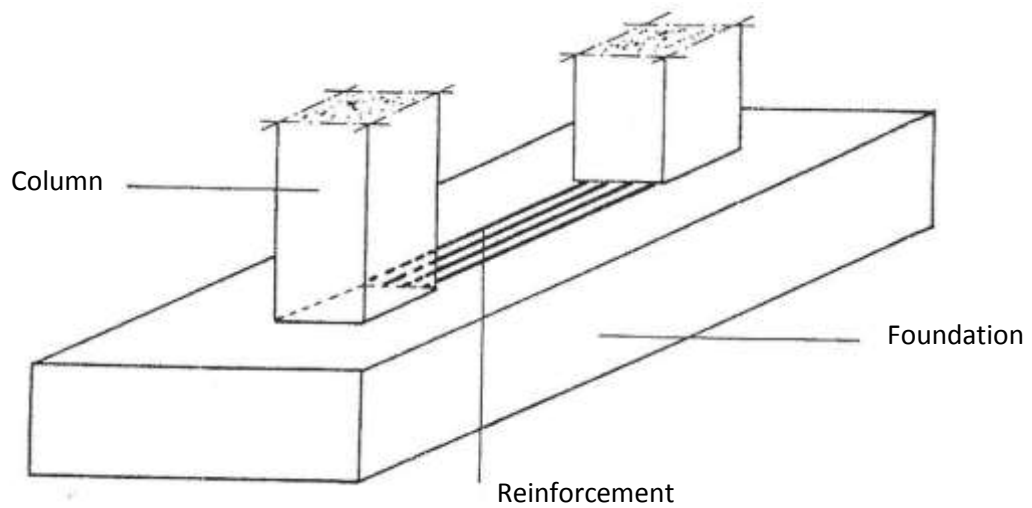


Figure 9. (Construction Technology notes, University of Alicante – Spain).

In this case, the easiest way for this foundation to be built is to construct a beam which catches all the columns and allows the right distribution of loads in all spans. This beam will be reinforced where needed.

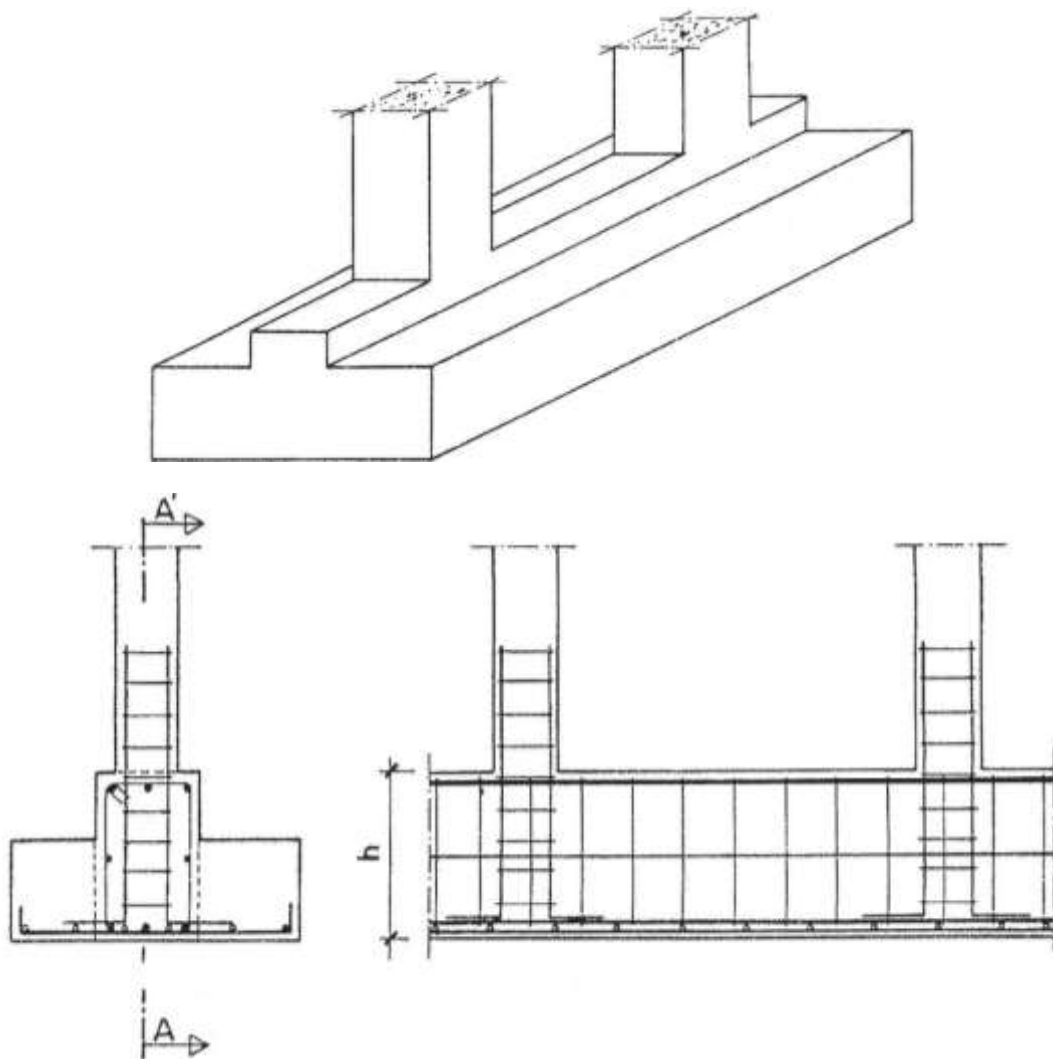


Figure 10. (Construction Technology notes, University of Alicante – Spain).

7.1.3 Raft foundations

This kind of foundation works distributing loads over the entire area of the site. So, the loads transmitted to the soil are considerably reduced. This method is particularly useful when the columns loads are heavy or the soil bearing capacity is low.

In this case, we have to think in slabs and their performance in load distribution. For that, we require distribution reinforcement in both ways (horizontal and vertical) and both sides (upper and lower).

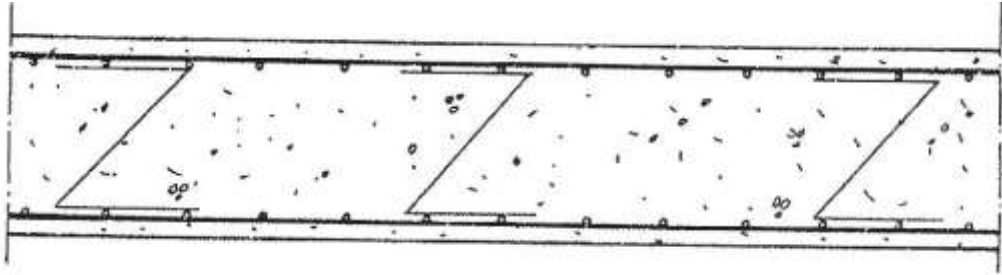


Figure 11. (Construction Technology notes, University of Alicante – Spain).

As columns transfer punctual loads, the slab is responsible for the distribution of these loads to the complete area. The deformation of this slab would be like this:

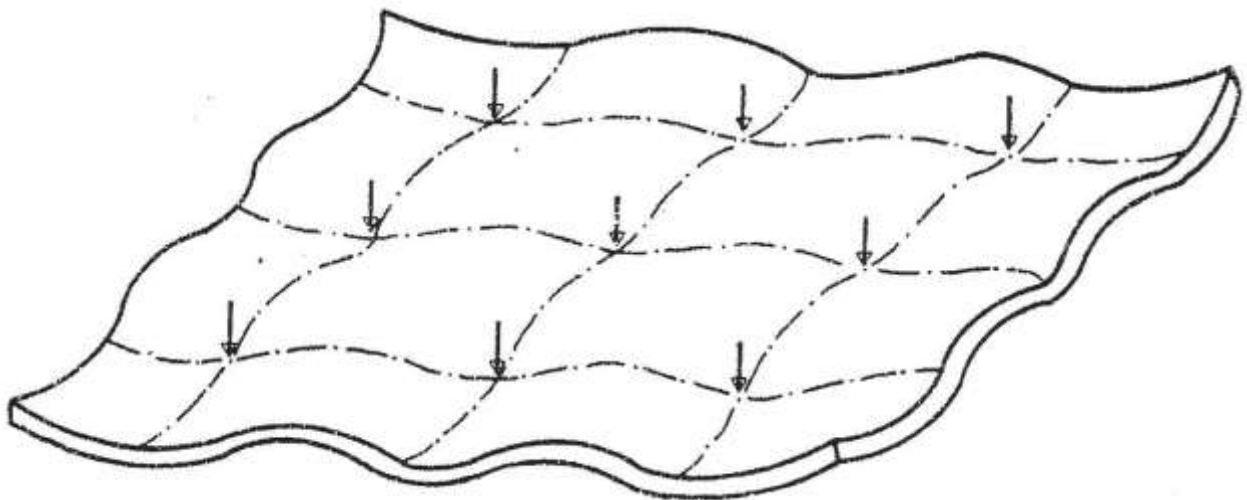


Figure 12. (Construction Technology notes, University of Alicante – Spain).

If we show one section of this slab by a row of columns, the bending moment diagram would be like this:

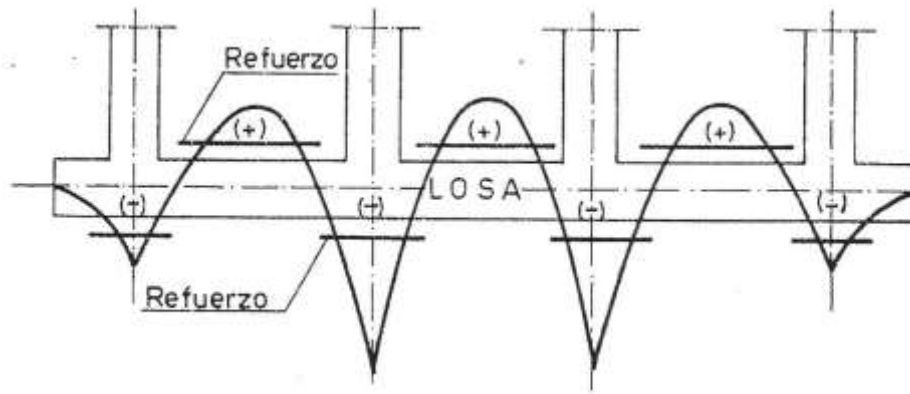


Figure 13. (Construction Technology notes, University of Alicante – Spain).

So, we can see the areas in which we need reinforcement, up and down. Doing the same operation in both ways, we obtain the distribution of reinforcement shown in the following upper and lower planes:

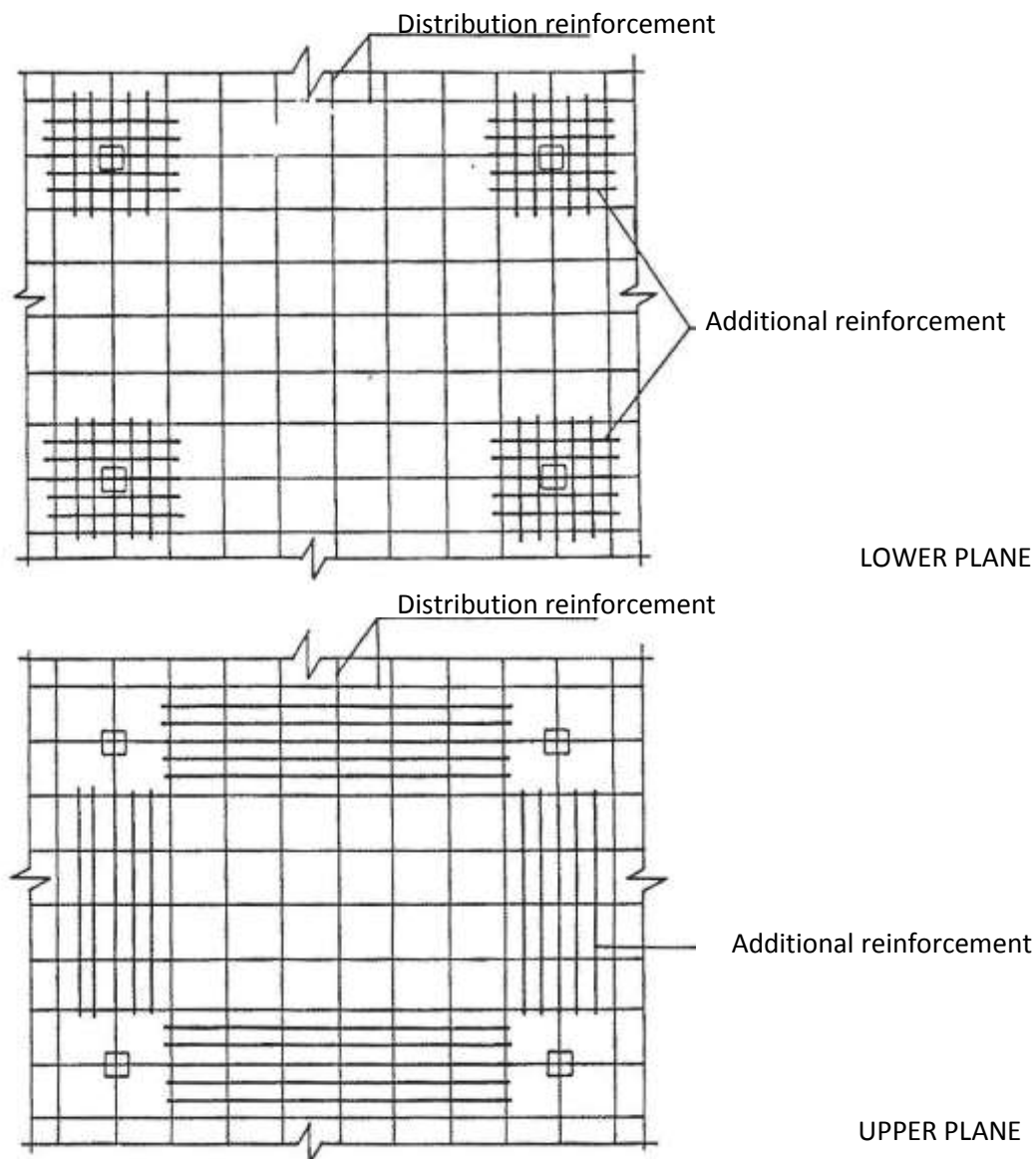


Figure 14. (Construction Technology notes, University of Alicante – Spain).

Columns generate important shear forces at the contact point with the slab, so probably we will need this reinforcement too. In the following perspective, we can see the different reinforcements we have inside the slab.

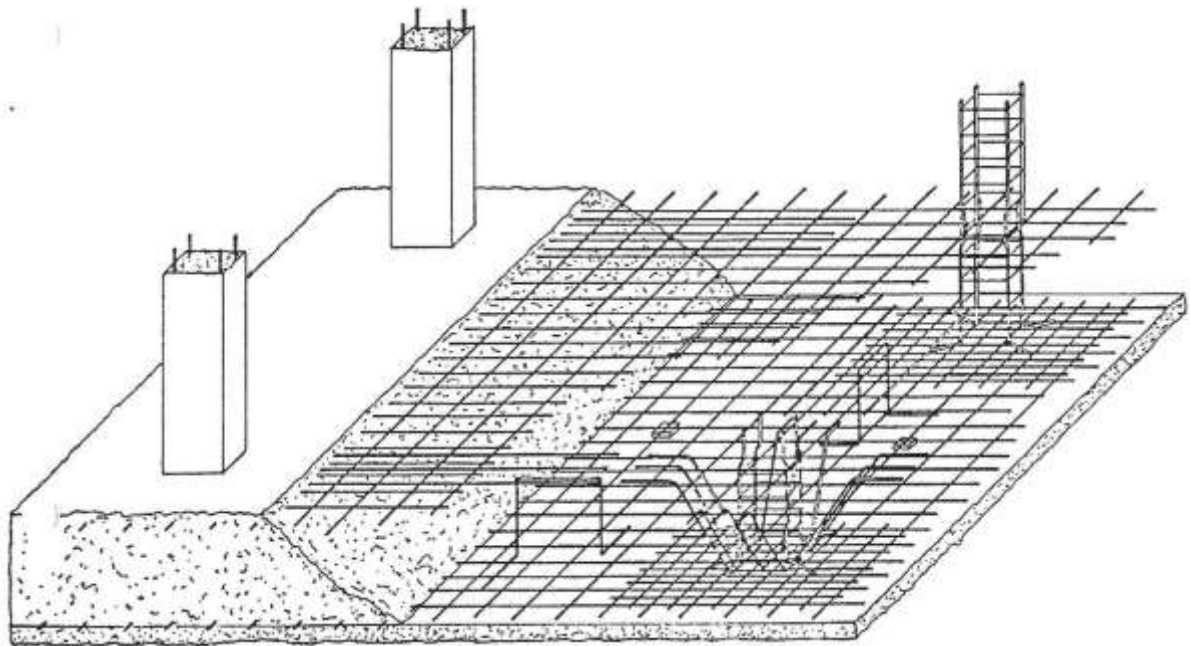


Figure 15. (Construction Technology notes, University of Alicante – Spain).

These are solid slab rafts, as they are constructed of uniform thickness over the whole raft. But we can also have beam and slab rafts, in which beams cross the slab through the rows of columns and distribute loads over the area of the raft. This usually results in a reduction of the slab thickness and, therefore, reduced expenses. Besides, these beams absorb the additional reinforcement and it is easier to build.

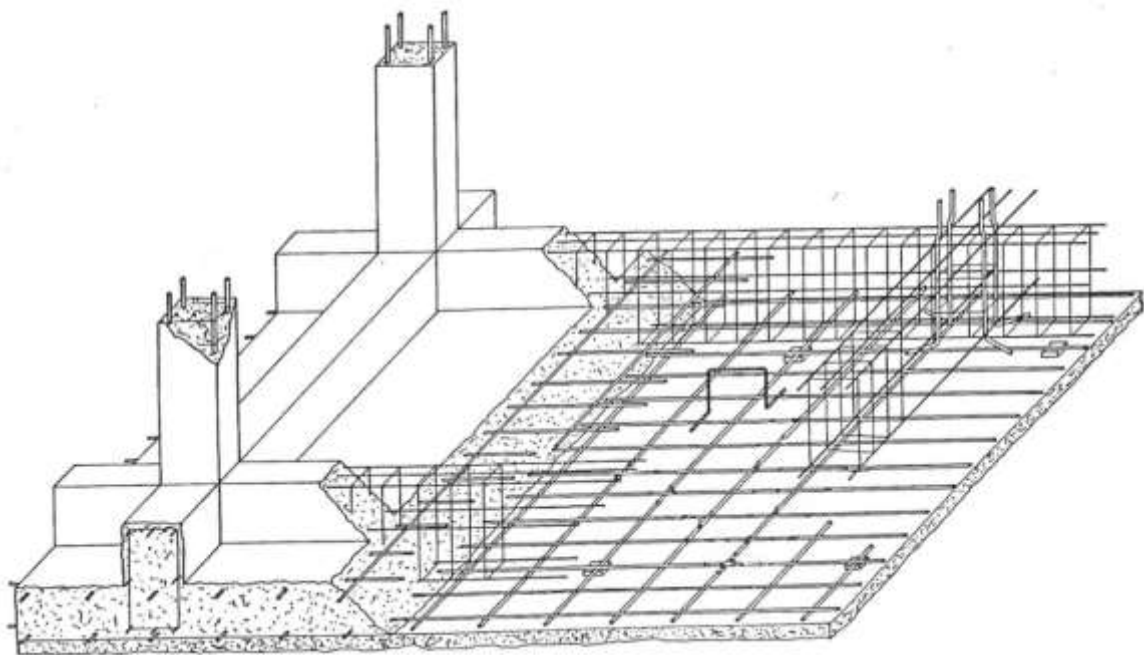


Figure 16. (Construction Technology notes, University of Alicante – Spain).

7.2 Deep foundations

7.2.1 Piles

A pile can be defined as a column inserted into the ground to transmit the structural loads to a lower level of subsoil. Piles are not necessarily the answer to all awkward foundation problems, but should be considered as an alternative to other techniques when suitable bearing capacity soil is not found near the lowest floor of the structure.

There are two ways they transmit their loads:

- a) The shafts of the piles act as columns carrying the loads through to a firm stratum.
- b) They work by friction (or adhesion) of the soil around the perimeter of the pile shaft.

In most cases, piles work on a combination of the two principles (c), but the major design consideration identifies the pile class.

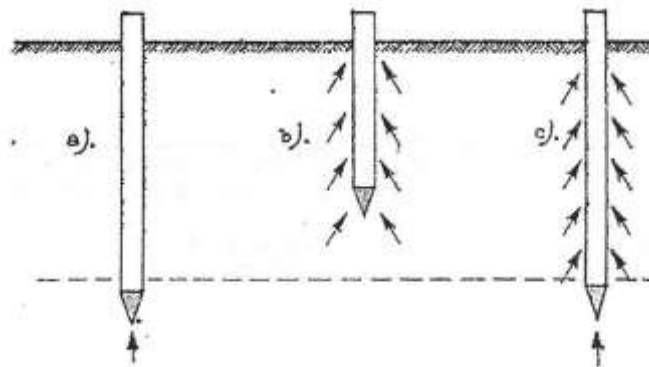


Figure 17. (Construction Technology notes, University of Alicante – Spain).

There are two main types of piles: displacement and replacement. A displacement pile is either drive, jacked, vibrated into the ground. This action displaces the soil outwards and downwards but material is not actually removed. On the other hand, the replacement pile consists of forming a hole in the ground and replacing the soil with concrete.

According to it, we establish the following classification:

Displacement piles		
Driven cast in situ	Permanent casing	
	Temporary casing	
Preformed	Concrete	
	Steel	
	Timber	
Replacement piles		
Supported	Permanent casing	
	Temporary casing	
Unsupported	Casing	
	Drilling mud	

Displacement piles

Driven cast in situ

It is used on medium to large contracts as an alternative to preformed piles particularly where the final length of pile is variable and must be determined on site.

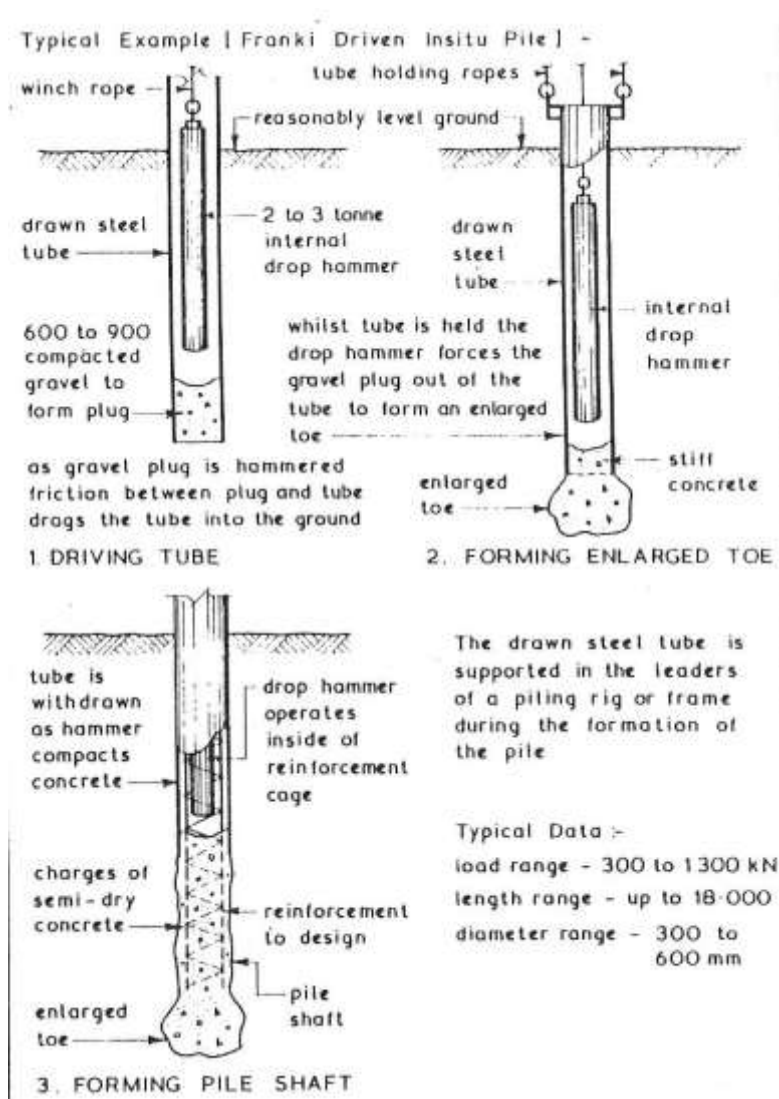


Figure 18. (John Greville's notes, UWTSD).

It is formed by driving a casing into the ground and filling the casing with concrete. If temporary casing is to be used, a heavy steel casing is closed at the end with a plug of concrete. The plug of concrete driven with a drop hammer expands, grips the sides of the casing and takes the casing into the ground. On reaching the required depth, the casing is restrained and the plug of concrete is driven out into the ground to form a bulb at the end of the pipe. A cage of reinforcement is placed and the casing is filled with concrete as the casing is withdrawn.

The permanent casing is usually formed with reinforced concrete shells and further shells may be added until the desired depth has been reached. Reinforced café and concrete may then be added.

Preformed piles

These piles are usually introduced in the ground by percussion driven, using a drop or single acting hammer. There is a large variety available, which are generally used when soft soil deposits overlie a firmer stratum.

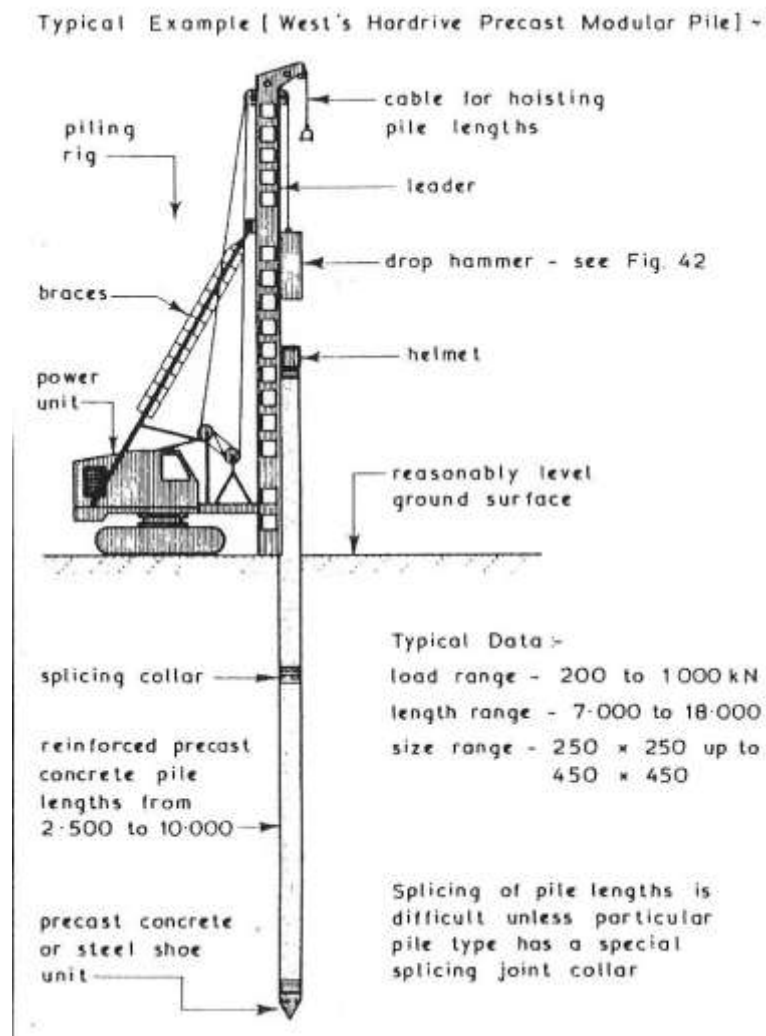


Figure 19. (John Greville's notes, UWTSD).

Care must be taken during driving to prevent damage to the pile by stresses exerted by the hammer. A further problem is the calculation of the length. The operation of lengthening piles is costly and shortening laborious. The handling of long concrete piles must be carefully supervised since incorrect handling may result in excessive stresses. The problem of lengthening pre-formed concrete piles has led to the development of precast modular piling. This system of piling consists of standard interchangeable precast piles with a unique jointing system. The piles, which vary in length from 2.5 to 10 m, incorporate steel connections at each end of the pile for simple assembly. Timber piles are not often used for permanent structural support in the UK, but they are frequently used for supported temporary platforms.

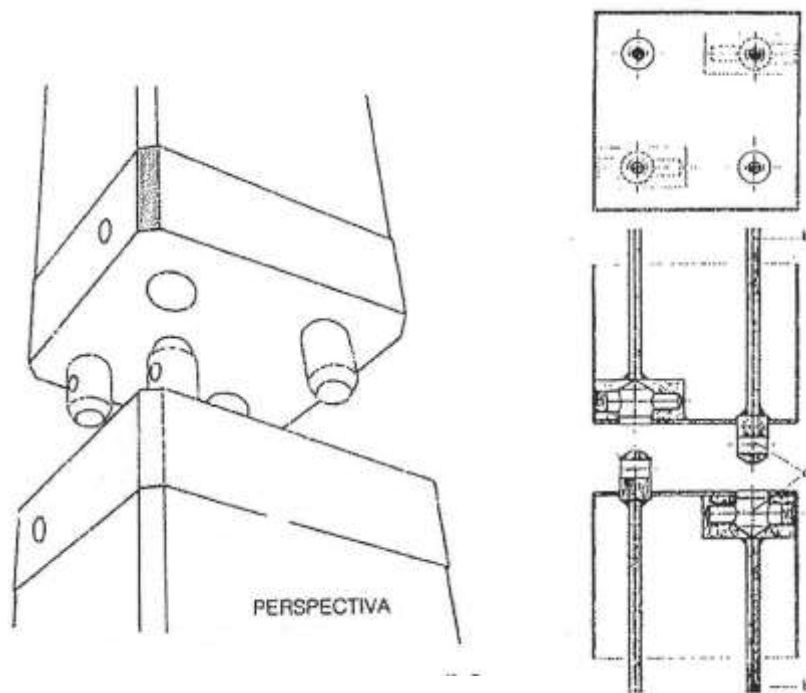


Figure 20. (Construction Technology notes, University of Alicante – Spain).

Replacement piles

Sometimes referred to as bored piles and formed by removing a column of soil and replacing with concrete on site or, in the case of composite piles, with precast and in situ concrete. In situ concrete is placed in the hole by means of a tremie pipe to prevent segregation of material.

The excavation can be supported or unsupported.

- The supported holes are provided with casing, a head of water or drilling mud so as to avoid falling. The casing can be provided by means of sectional elements screwed together as boring proceeds.
- The unsupported hole will normally require a short tube at the top to prevent debris from falling into the concrete during placing.

The formation of this type of piles can be considered under two general classifications: the percussion bored and the rotary bored.

- Percussion bored pile: a steel tube made up of lengths 1 – 1.4 m screwed together is sunk by extracting the soil from within the tube liner using percussion cutters or balers, according to the nature of the subsoil to be penetrated. The steel lining tube will usually sink under its own weight but it can be driven in with slight pressure.
- Rotary bored pile: the rotary bored pile is suitable for most cohesive soils such as clay and is formed using an auger which may be operated in conjunction with the steel tube liner, according to the subsoil conditions encountered. An adaptation of the rotary bored pile is known as the flush bored. These are basically rotary bored piles using bentonite as a drilling fluid.

7.2.1.1 Pile testing

The main problem with piles is to guarantee that they are going to resist the expected loads. Pile testing is then one important tool to foresee the proper performance. There are five main types of testing:

Maintained Load (MLT) Test

In the MLT, the load is applied to the pile in discrete increments and the resulting pile movement/settlement monitored. Subsequent load increments are only applied when the minimum specified time period has elapsed and the rates of induced settlement are below the specified criteria. The normal U.K. practice is to load the pile up to the design Verification Load (DVL), then to unload back to zero loading. Subsequent load cycles are applied, taking the loading to specified values above the DVL depending on the requirements of the test. The test will normally last between 24 and 48 hours excluding erecting and dismantling the test equipment.

The MLT method is normally the most suitable in determining the load/settlement performance of a pile under working loads and at 1.5 times working load conditions.

Constant Rate of Penetration (CRP) Test

In the CRP test, the load required to cause a pile to penetrate into the ground at a constant rate is monitored until either the maximum specified test load is achieved or "failure" of the pile occurs. The performance of the test takes less than 24 hours excluding erecting and dismantling the test equipment.

The measured penetration of the pile is plotted against the load applied, the purpose of the test being to determine the ultimate bearing capacity of the pile, particularly for piles constructed within predominantly cohesive material and deriving their capacity mainly in shaft friction. However, due to the high rate of loading, the measured maximum soil resistance may over-predict the ultimate capacity.

Bi-directional Load Cell

Another form of MLT uses a bi-directional load cell. This system is usually only applicable to conventional auger bored piles carrying high axial loads. The method involves a load cell or cells placed in the pile bore either at the pile base or part of the way up the pile shaft during the concreting operation. In the test the cell is hydraulically expanded so the upper part of the pile reacts against the lower part.

Rapid Load Test

Rapid Load Tests use a combustion chamber to provide a rapid load application to the pile head. The length of the stress wave in these tests is sufficiently long to encompass the whole pile and therefore there is no need for complex wave equation analysis when interpreting the results. However, in common with the dynamic load test, effects of creep and pore water dissipation can influence the results although to a slightly lesser extent because the rate of loading is lower.

Dynamic Load Test

These methods are based on monitoring the response of a pile subjected to hammer blows applied at the pile head. The measured response parameters are subsequently analysed to give predictions of the soil resistance that would be mobilised by the pile under static load conditions, based on stress wave theory. The analytical models of the pile/soil interaction have been further developed to provide prediction of the load/settlement performance of the tested pile.

Developed initially for use with driven piles and now universally accepted, dynamic load testing of cast in place piles is now quite widely used to predict the static soil resistance and the load/settlement behaviour. The test method is similar to that used on driven piles with the monitoring of hammer blows and subsequently analysing the pile response to the stress wave propagation. A separate hammer or drop weight is usually brought to site to allow the dynamic load to be applied to a cast in place pile.

Due to the very high rate of applied loading, dynamic load testing cannot take into account time-related effects such as consolidation, relaxation or creep. Typically a dynamic test will take about 15 minutes to perform on a precast concrete pile using the piling rig hammer to 30 minutes on a bored cast in place pile requiring the use of a separate drop weight.

7.2.2 Pile caps

Piles are not usually used singly but are formed into a group or cluster. The load is distributed over the heads of the piles in the group by means of a reinforced cast in situ concrete pile cap. To assist continuity the heads of piles penetrate the base of the pile cap some 100-150 mm.

The main reinforcement is two-directional and, in many piling schemes, especially where capped single piles are tied together with reinforced concrete tie beams. The beams can be used to carry loadings such as walls to the pile foundations.

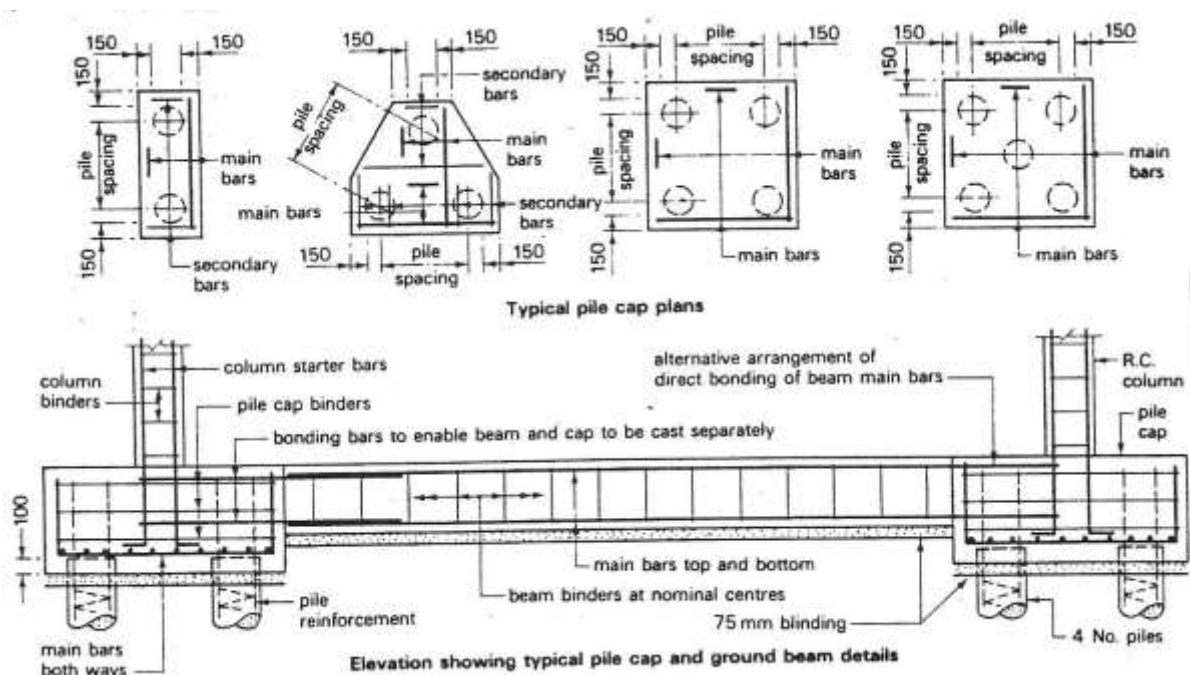


Figure 21. (John Greville's notes, UWTSD).

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