Foundations

Introduction

This chapter explains the principles and practice of house foundations and summarises the major causes of foundation failure. The chapter is divided into two sections; the first concentrates on the general factors which affect the choice of foundation and the second considers appropriate solutions for specific ground conditions.

SECTION ONE
General Factors Which Affect the Choice of Foundation

Function

The foundations of houses must carry the dead loads of the walls, roof and floors etc., together with the imposed loads of occupants and furniture and transmit them safely into the ground. They must be designed so that settlement is sufficiently controlled to keep any distortion (and possibly cracking) to within acceptable limits.

Terminology

This chapter is not intended as a technical manual and we have consciously tried to avoid unnecessary emphasis on detail. However, there are some basic definitions commonly misunderstood and misused and it is important that you spend a little time familiarising yourself with these before continuing.

Bearing Pressure The pressure on the soil caused by the building load.

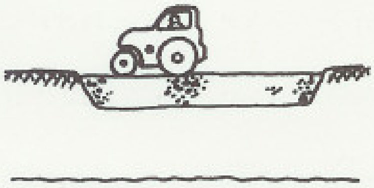
Bearing Capacity The load which the ground can carry.

Subsidence Downward movement of the ground caused by the imposition of internal forces eg, water, mining works.

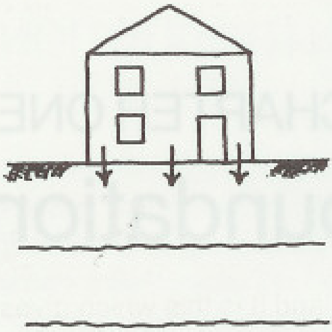
Settlement Downward movement of the ground, or any structure on it, due to soil consolidation, normally caused by the load applied by the structure.

Compaction The act of increasing the density and strength of a material by the application of impact forces eg, a heavy roller.

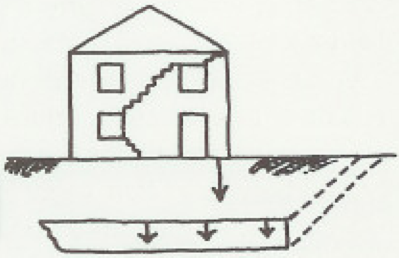
Consolidation The act of increasing the density and strength of the soil by the expulsion of water and air under self-weight and constant external loading.



Compaction by roller



The building settles as the ground consolidates under load

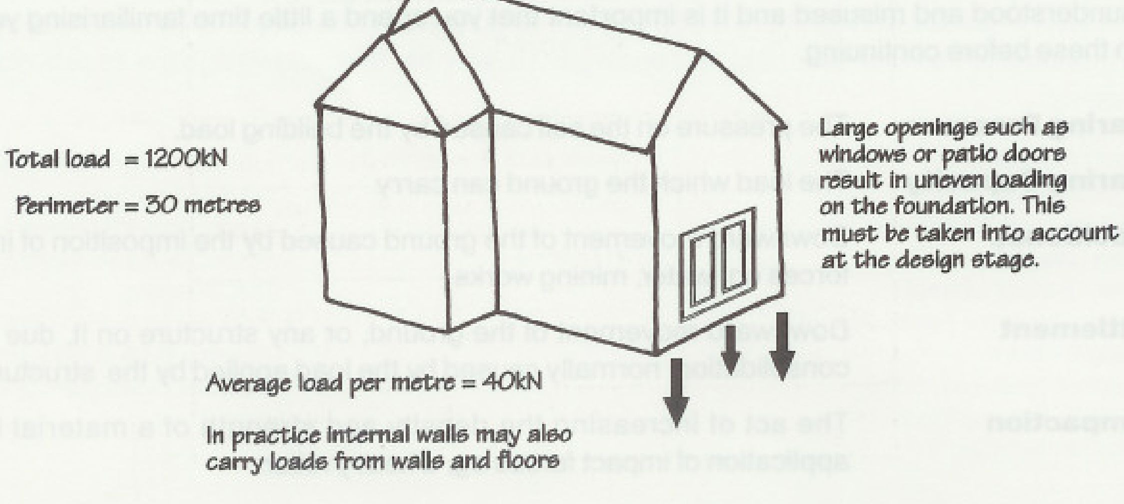


Subsidence caused by mining works

Building Load

For a typical modern three-bedroom detached house the total of the dead and imposed loads is about 120tonnes and most types of ground can easily carry this load using simple foundations. The exact dead and imposed loads can be calculated using simple tables produced by the British Standards Institution. When designing buildings, engineers are primarily concerned with forces rather than weights and the unit of force most commonly used is the kilonewton (1tonne is roughly equal to 10kilonewtons). Therefore, the building load of 120tonnes exerts a force on the ground of 1200kN. If all the load is carried by the external walls and the perimeter of the building is 30 metres, simple calculation shows that each metre run at ground level is carrying about 4tonnes or 40kN. In practice, allowance must be made for the nature of the loading which varies according to the direction of roof and floor spans. Furthermore, uneven loading can be caused by large openings such as patio doors.

Once the average loading per metre run of the building is established it must then be related to the safe bearing capacity of the ground in order to enable the design of an appropriate foundation.



Soils

Most soils consist of a mixture of solid particles, water and air. In addition, the soil near the surface of the ground will also contain organic material and this top soil must never be used as a base for a foundation. It varies greatly in volume due to changes in water content and is very unstable due to the amount of organic material it contains.

Before construction commences the top soil (about 150–300mm thick) should be removed from the site or stockpiled for future landscaping.

Below the top soil lies the subsoil (often referred to as soil) and it is this which actually supports the building. Apart from organic soils and rock there are two broad categories of soil type: cohesive and non-cohesive. Cohesive soils are those, such as clay and silt, with microscopic particle size and which can contain very high levels of water. The shape of the tiny particles makes them cling together trapping water in between and it is this which gives clays their characteristic smooth, sticky feel. Non-cohesive soils such as sands and gravels contain negligible amounts of water and have large particle sizes which are held together mainly by their weight. Unlike clays they do not stick together and the soils are very loose in structure.

Soils Under Load

Increasing the pressure on a soil by applying the load of a building squeezes some of the water out of the soil causing it to consolidate and allowing slight settlement of the structure above. In non-cohesive soils such as sands water movements are rapid and a building will normally complete its settlement during its construction. In addition, because sands only contain a very small amount of water any settlement will be minimal. Cohesive soils such as clay lose their water much more gradually and buildings may slowly settle for many years before equilibrium is reached. The softer clays contain large amounts of water and thus permit extensive settlement.

Soil Types

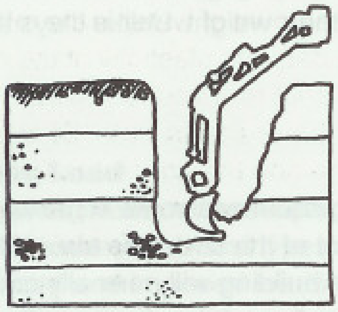
There is a wide range of soil types in the UK ranging from rocks such as granite and limestone which can support very high loads down to soft clay and silt which often require specialist foundation techniques due to their low bearing capacity.

The table below summarises some of the common soils and their suitability for house foundations.

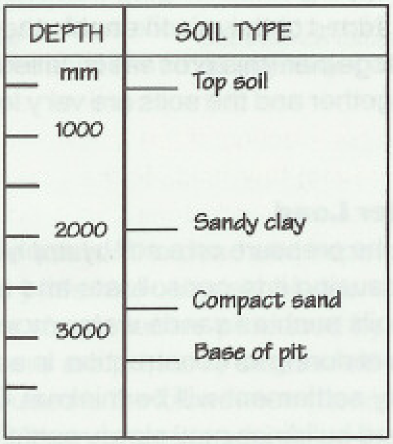
GROUND	COMMENTS
Granite Limestone Sandstone Slate Hard Chalk	Require pneumatic or hydraulic tools for excavation but generally provide good support
Compact sands Gravels	Can be excavated by machine without special tools. Provide good support
Firm & stiff clays Sandy clays	Can be excavated by hand or machine. May require wider foundations than sands and gravels
Loose sand Soft silt Soft clay	Easy to excavate but may need specially designed foundations
Peat Topsoil	Generally unsuitable for foundations

Site Investigation

Although geological maps can give a general guide to soil types, in particular locations a more detailed site analysis will be required to determine the actual properties of the soil and identify any other factors which will affect the foundation design. The site investigation should include details of the site topography, the level of ground water, the type of vegetation present (or recently removed), the previous use of the site and, of course, the type of ground. In order to assess the nature of the ground trial pits can be excavated across the site and the sides of the excavation inspected. By reference to simple tables the safe bearing capacity of the soil can be assessed and this, together with the building load, will form the basis of the foundation design. For blocks of flats or commercial buildings more sophisticated techniques are necessary due to the increased load.

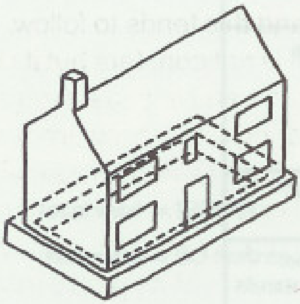


Trial pits excavated; depth determined by nature of ground.



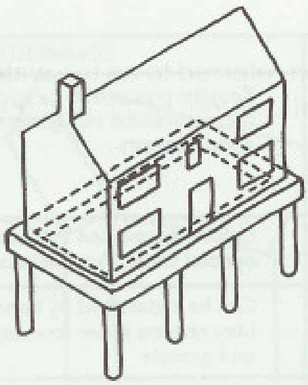
Foundation Types

There are three basic types of foundation used in housing and these are shown in the diagrams below. Of the three, the strip foundation is by far the most common.



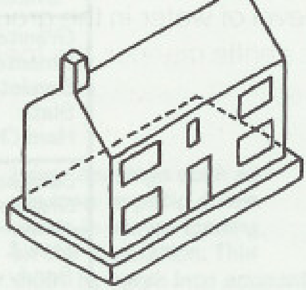
Strip Foundation

Strip of concrete under all load-bearing walls; width of strip dependent on ground bearing capacity and building load.



Piled Foundation

Long slender concrete members used to transfer loads through weak or unstable soil to ground of higher bearing capcity



Raft Foundation

Concrete raft which spreads loads over whole ground floor area

Concrete

Concrete, as we know it today, is a relatively recent material and has only been common in foundations for just over 100 years. In its simplest form it is a mixture of cement, stone and water mixed in varying proportions. By increasing the amount of cement concretes of increased strength can be formed. The stone which forms the bulk of the mixture (often referred to as the aggregate) should be graded to ensure a reasonable balance of small and large particle sizes. This ensures that the concrete is free from voids as the smaller grains fill the spaces between the larger grains, and, in addition provide a strong workable mix with the minimum of cement. To ensure that the proportions and grading of the aggregate are correct it is delivered separately to the site or concrete plant as fine aggregate (sand) and coarse aggregate (stone or chippings). It can then be mixed as required. Fine aggregate has particles which run through a 5mm sieve and coarse aggregate has particles ranging from 5mm to 38mm depending on the purpose of the concrete.

Water is added to the mix to enable the chemical reaction to occur which binds the cement and aggregate together (this process is called hydration). The correct amount of water is the minimum to ensure completion of the chemical reaction and, in addition, adequate plasticity of the mix for placing and compacting. If too much water is added the excess (not required for hydration) will evaporate leaving tiny voids in the concrete which seriously reduces its strength. Of course, if insufficient water is added complete hydration will not take place and the concrete will be very difficult to place and compact. In good conditions a well-proportioned concrete will set within a few hours and will reach full strength after several weeks. Because of concrete's high strength, bricklayers can usually start building on the foundations a few days after it has been poured.

There are various ways of specifying concrete. The Building Regulations require a minimum mix ratio of 50kg of cement to 0.10m^3 sand and 0.2m^3 stone for simple strip foundations. This is often referred to as a 1:3:6 mix. Stronger mixes are often referred to as 1:2:4 or 1:1$\frac{1}{2}$:3. An alternative method is to state the finished strength of concrete and, in recent years, this has become the normal method of specification. A C30 mix for example will achieve a crushing strength of 30 N/mm^2 after 28 days. In addition the specification could include the type of cement and the aggregate size.

Other Considerations

After determining the building load and the nature of the ground there are some other important considerations which may affect the foundation design.

The Water Table

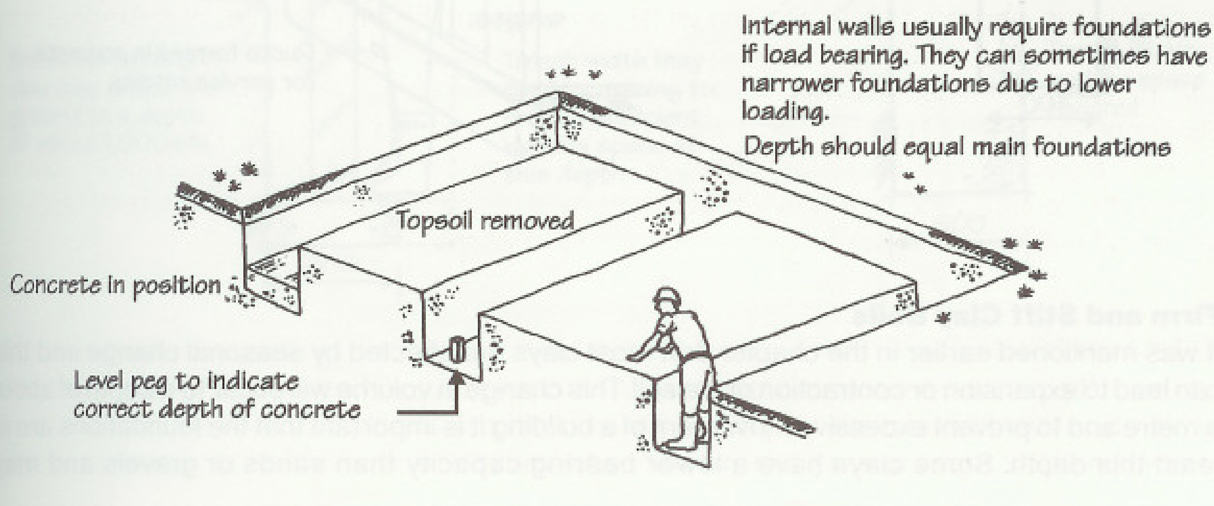
The level of water in the ground is often referred to as the water table and this tends to follow, in a more gentle manner, the topographical features of the surface above. It is not constant but it rises and falls with variations of rainfall, atmospheric pressure and temperature and in coastal regions can be affected by tides. When the water table reaches the surface, springs, lakes, swamps and similar features can be formed. In most cases the water table will be below the depth required by traditional strip foundations and it will have little effect on their construction. However, occasionally high water tables will be found and this can lead to extra expense pumping out the trenches while the concrete is being poured and, in some grounds, can lead to problems of sulphate attack. Calcium, Magnesium and Sodium sulphates which occur naturally in some clays can, in wet conditions, attack the concrete and cause severe deterioration of the foundation. In areas with a high water table the sulphates can dissolve in the ground water and permeate the concrete. This leads to a chemical reaction between the sulphates in solution and one of the chemicals in the cement. The resulting compound expands rapidly as it forms and this can crack the foundation concrete. If sulphate attack is a possibility it is wise to use sulphate resisting cement.

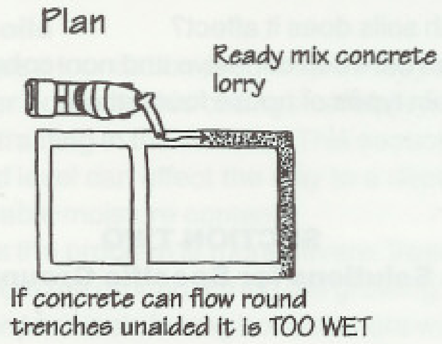
Compact Sands and Gravels

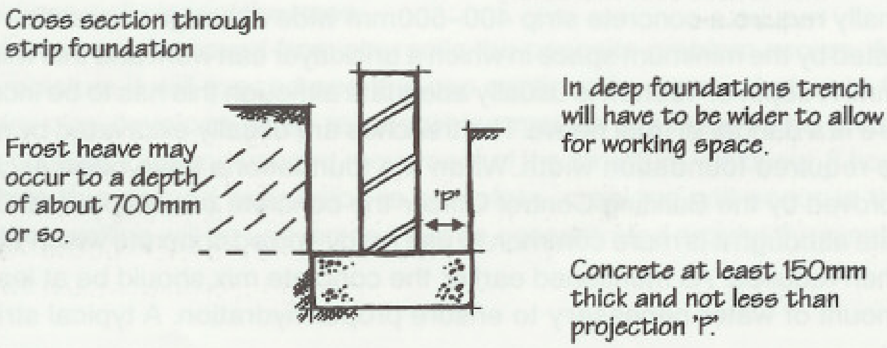
These soils can easily carry the weight of two- and three-storey houses using simple strip foundations. A table in the Building Regulations indicates acceptable minimum widths of the concrete strip depending on the load and the type of ground. For sands and gravels two-storey houses normally require a concrete strip 400–500mm wide although in practice the width of the trench is dictated by the minimum space in which a bricklayer can work and this will usually require at least 600mm. A depth of 450mm is usually adequate although this has to be increased to about 700mm if there is a danger of frost heave. The trenches are usually excavated by machine using a bucket of the required foundation width. When the foundations have been excavated and the trenches approved by the Building Control Officer the concrete can be poured. Concrete can be batched on site although it is more common to use ready-mixed concrete which will be brought on to the site when required. As mentioned earlier the concrete mix should be at least 1:3:6 with the minimum amount of water necessary to ensure proper hydration. A typical strip foundation is shown below.

An alternative solution is to use trench fill and this method is often preferred by builders as it avoids the need for working space and trench support with obvious savings in the costs of excavation and soil disposal. As mentioned previously most sands and gravels can safely support low-rise housing with a concrete strip only 400–500mm wide and such soils are therefore ideal for this form of construction. There are two potential problems. First, if the trench is not cut dead straight and in exactly the right position the bricklayers will have difficulty in setting out the walls. Second, it is important to leave ducting through the concrete for service connections which are required below the finished concrete level.

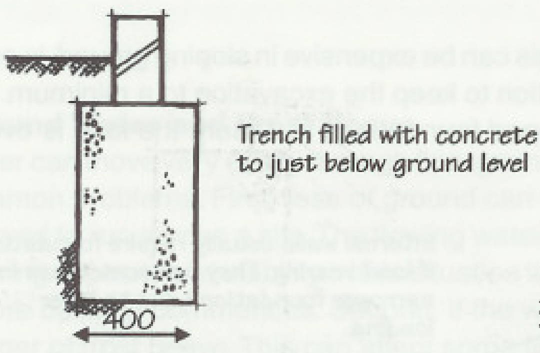
Foundations obviously have to be laid level and this can be expensive in sloping ground. In order to reduce the cost it is possible to 'step' the foundation to keep the excavation to a minimum. The Building Regulations contain simple rules for stepped foundations to ensure the load is evenly

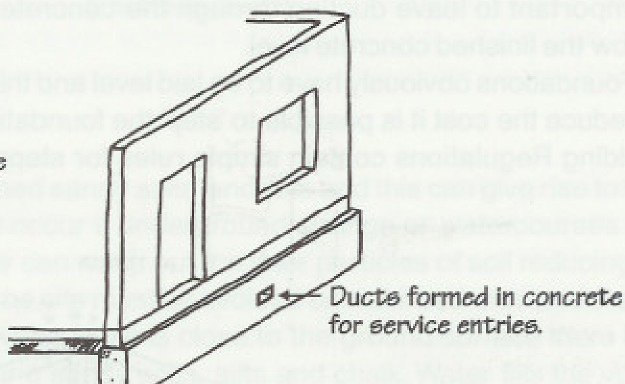






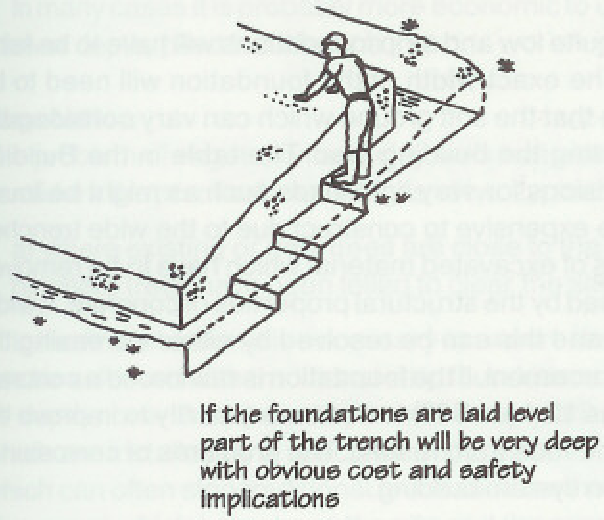
distributed over the ground and to prevent cracking at the step itself. These are shown in the diagram below.

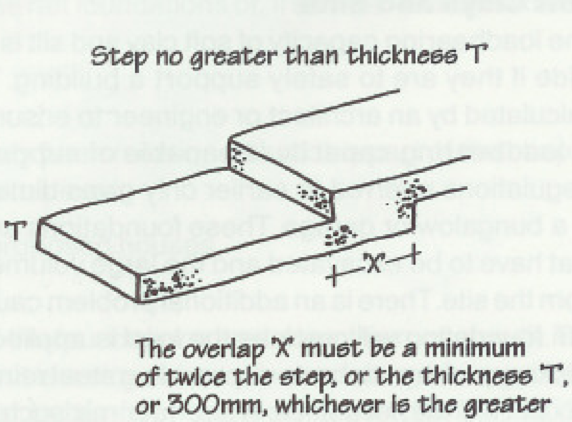




Firm and Stiff Clay Soils

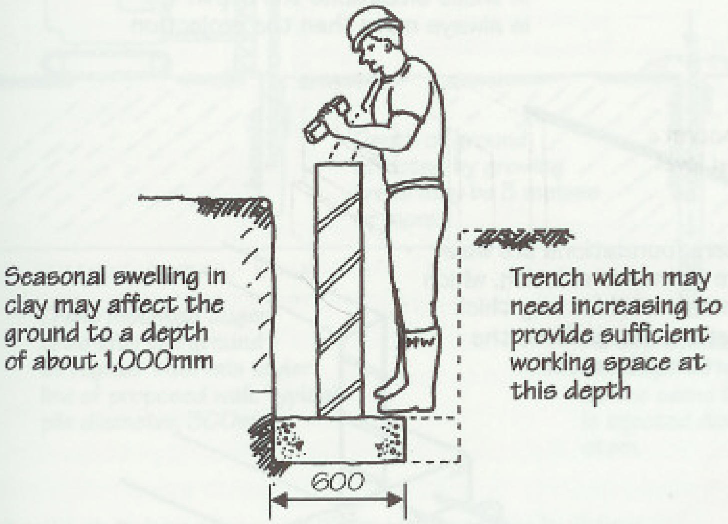
It was mentioned earlier in the chapter that most clays are affected by seasonal change and this can lead to expansion or contraction of the soil. This change in volume will occur to a depth of about a metre and to prevent excessive movement of a building it is important that the foundations are at least this depth. Some clays have a lower bearing capacity than sands or gravels and may

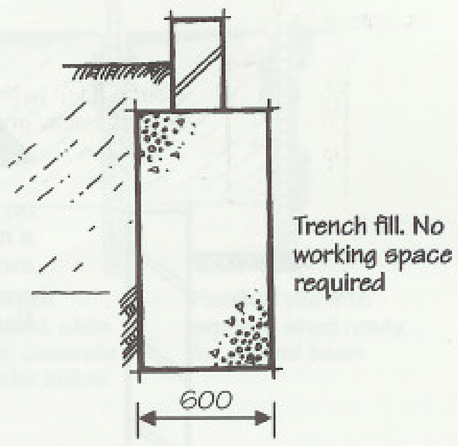




therefore require slightly wider foundations in order to spread the load over a sufficiently large area of ground. 600mm is usually sufficient for normal two-storey buildings. If trees are growing on the site in close proximity to the building (or have recently been felled) this form of construction is generally not suitable and appropriate solutions are described in a later section. As in the previous example trench fill can be used to avoid the need for working space and to keep the trench width to a minimum.

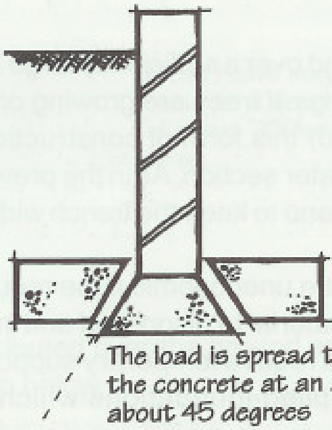
In practice both traditional strip and trench fill foundations become uneconomic if the required depth is more than 1000mm. There is a large volume of excavated material to dispose of and in wet weather the open trenches need constant cleaning out and may well require temporary support to prevent the banks collapsing. A sensible alternative is to use piled foundations which are mentioned in a later section.





Soft Clays and Silts

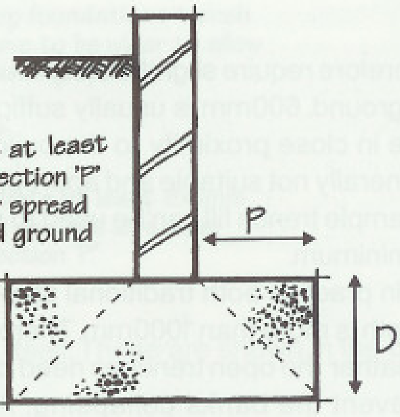
The loadbearing capacity of soft clay and silt is quite low and strip foundations will have to be fairly wide if they are to safely support a building. The exact width of the foundation will need to be calculated by an architect or engineer to ensure that the soft ground which can vary considerably in loadbearing capacity is capable of supporting the building load. The table in the Building Regulations referred to earlier only gives dimensions for very light loads such as might be found in a bungalow or garage. These foundations are expensive to construct due to the wide trenches that have to be excavated and the large volumes of excavated material which have to be removed from the site. There is an additional problem caused by the structural properties of concrete. A wide, thin foundation will crack as the load is applied and this can be resolved by either increasing the thickness of the concrete or providing steel reinforcement. If the foundation is reinforced a concrete mix of 1:3:6 will not suffice. A stronger mix such as 1:2:4 (or C28) is necessary partly to improve the bond with the steel rods and partly to prevent the rods from rusting. The problems of corrosion in steel reinforcement are covered in the chapter on system building.



The load is spread through the concrete at an angle of about 45 degrees

Wide thin foundations can crack in the manner shown. This is known as shear failure.

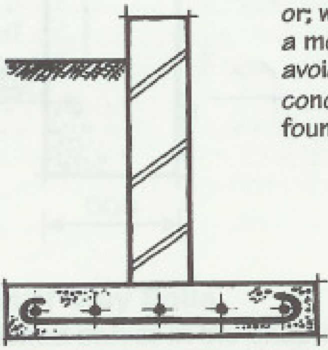
If the depth 'D' is at least equal to the projection 'P' the load is safely spread over the intended ground area.



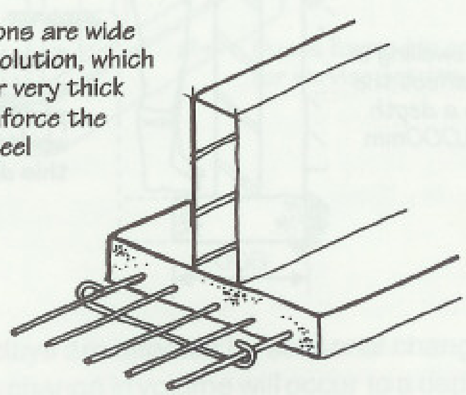
In practice, many strip foundations are either quite narrow and/or quite deep.

In these situations the depth is always more than the projection

or; where foundations are wide a more economic solution, which avoids the need for very thick concrete, is to reinforce the foundation with steel



Steel prevents cracking from occuring



Steel bars run along, and across, the wide strip foundation