3 Groundwork and Foundations

The foundation of a building is that part of walls, piers and columns in direct contact with, and transmitting loads to, the ground. The building foundation is sometimes referred to as the artificial foundation, and the ground on which it bears as the natural foundation. Early buildings were founded on rock or firm ground; it was not until the beginning of the twentieth century that concrete was increasingly used as a foundation base for walls. With the introduction of local and then national building regulations, standard forms of concrete foundations have become accepted practice in the UK, along with more rigorous investigation of the nature and bearing capacity of soils and bedrock.

3.1 Functional requirements

The primary functional requirement of a foundation is strength and stability.

Strength and stability

The combined, dead, imposed and wind loads on a building must be transmitted to the ground safely, without causing deflection or deformation of the building or movement of the ground that would impair the stability of the building and/or neighbouring structures. Foundations should also be designed and constructed to resist any movements of the subsoil.

Foundations should be designed so that any settlement is both limited and uniform under the whole of the building. Some settlement of a building on a soil foundation is inevitable. As the building is erected the loads placed on the foundation increase and the soil is compressed. This settlement should be limited to avoid damage to service pipes and drains connected to the building. Bearing capacities for various rocks and soils are assumed and these capacities should not be exceeded in the design of the foundation to limit settlement.

3.2 Bedrock and soil types

Ground is the general term for the Earth's surface, which varies in composition within the two main groups: rocks and soils. Rocks include hard, strongly cemented deposits such as granite, and soils the loose un-cemented deposits such as clay. Rocks suffer negligible compression and soils measurable compression under the imposed load of a building. The size and depth of a foundation is determined by the structure and size of the building it supports and also the nature and bearing capacity of the ground supporting it.

Rocks

Rocks may be divided into three broad groups as igneous, sedimentary and metamorphic.

Igneous rocks

Igneous rocks, such as granite, dolerite and basalt, are those formed by the fusion of minerals under great heat and pressure. Beds of strong igneous rock occur just below or at the surface of the ground in Scotland and Cornwall as Aberdeen and Cornish granite respectively. The nature and suitability of such rocks as a foundation may be distinguished by the need to use a pneumatic drill to break up the surface of sound, incompressible rock to form a roughly level bed for foundations. Because of the density and strength of these rocks it would be sufficient to raise walls directly off the rock surface. For convenience it is usual to cast a bed of concrete on the roughly levelled rock surface as a level surface on which to build. The concrete bed need be no wider than the wall thickness it supports.

Sedimentary rocks

Sedimentary rocks, such as limestone and sandstone, are those formed gradually over thousands of years by the settlement of particles of calcium carbonate or sand to the bottom of bodies of water where the successive layers of deposit have been compacted as beds of rock by the weight of water above. Because of the irregular and varied deposit of the sediment, these rocks were formed in layers or laminae. In dense rock beds the layers are strongly compacted and in others the layers are weakly compacted and may vary in the nature of the layers and so have poor compressive strength. Because of the layered nature of these rocks the material should be laid as a building stone with the layers at right angles to the loads.

Metamorphic rocks

Metamorphic rocks such as slates and schists are those changed from igneous, sedimentary rocks or from soils into metamorphic rocks by pressure or heat or both. These rocks vary from dense slates in which the layers of the material are barely visible to schists in which the layers of various minerals are clearly visible and may readily split into thin plates. Because of the mode of the formation of these rocks the layers or planes rarely lie horizontally in the ground and so generally provide an unsatisfactory or poor foundation.

Soil

Soil is the general term for the upper layer of the Earth's surface that consists of various combinations of particles of disintegrated rock, such as gravel, sand or clay, with some organic remains of decayed vegetation generally close to the surface.

Topsoil
The surface layer of most of the low-lying land in the UK that is most suited to building, consists of a mixture of loosely compacted particles of sand, clay and an accumulation of decaying vegetation. This layer of topsoil, which is about 100 to 300 mm deep, is sometimes referred to as vegetable topsoil. It is loosely compacted, supports growing plant life and is unsatisfactory as a foundation because of its poor bearing capacity. It should be stripped from the site and retained for landscaping around the site.

Subsoil
Subsoil is the general term for soil below the topsoil. It is unusual for a subsoil to consist of gravel, sand or clay by itself. The majority of subsoils are mixes of various soils. Gravel, sand and clay may be combined in a variety of proportions. To make a broad assumption of the behaviour of a particular soil under the load on foundations it is convenient to group soils such as gravel, sand and clay by reference to the size and nature of the particles. The three broad groups are coarse-grained non-cohesive, fine-grained cohesive and organic. The nature and behaviour under the load on foundations of the soils in each group are similar.

Coarse-grained non-cohesive soils
Soils that are composed mainly of, or combinations of, sand and gravel consist of largely siliceous, unaltered products of rock weathering. They have no plasticity and tend to lack cohesion, especially when dry. Under pressure of the loads on foundations the soils in this group compress and consolidate rapidly by some rearrangement of the coarse particles and the expulsion of water. A foundation on coarse-grained non-cohesive soils settles rapidly by consolidation of the soil as the building is erected, so that there is no further settlement once the building is completed.

Gravel consists of particles of a natural coarse-grained deposit of rock fragments and finer sand. Many of the particles are larger than 2 mm. Sand is the natural sediment of granular, mainly siliceous, products of rock weathering. Particles are smaller than 2 mm, are visible to the naked eye and the smallest size is 0.06 mm. Sand is gritty, has no real plasticity and can easily be powdered by hand when dry. Dense, compact gravel and sand requires a pick to excavate for foundation trenches.

Fine-grained cohesive soils
Fine-grained cohesive soils, such as clays, are a natural deposit of the finest siliceous and aluminous products of rock weathering. Clay is smooth and greasy to the touch, shows high plasticity, dries slowly and shrinks appreciably on drying. Under the pressure of the load on foundations clay soils are very gradually compressed by the expulsion of water through the very many fine capillary paths, so that buildings settle gradually during building work and this settlement may continue for some years after the building is completed. The initial and subsequent small settlement by compression during and after building on clay subsoils will generally be uniform under most small buildings, thus no damage is caused to the structure and its connected services.

3.3 Ground movement

Approved Document A states that the building shall be constructed so that ground movement caused by swelling, shrinkage or freezing of the subsoil, or land-slip or subsidence, which can be reasonably foreseen, will not impair the stability of the building. The foundations of the building must be selected and designed so that they overcome the problems of ground movement.

Volume change

Firm, compact shrinkable clays suffer appreciable vertical and horizontal shrinkage on drying and expansion on wetting due to seasonal changes. Seasonal volume changes under grass extend to about 1 m below the surface in Great Britain and up to depths of 4 m or more below large trees. The extent of volume changes, particularly in firm clay soils, depends on seasonal variations and the proximity of trees and shrubs. The greater the seasonable variation, the greater the volume change. The more vigorous the growth of shrubs and trees in firm clay soils, the greater the depth below surface the volume change will occur. As a rough guide it is recommended that buildings on shallow foundations should not be closer to single trees than the height of the tree at maturity, and one-and-a-half times the height at maturity of groups of trees, to reduce the risk of damage to buildings by seasonal volume changes in clay subsoils.

When shrubs and trees are removed to clear a site for building on firm clay subsoils there will, for some years after the clearance, be ground recovery as the clay gradually recovers moisture previously taken by the shrubs and trees. The design and depth of foundations of buildings must allow for this gradual expansion to limit damage by differential settlement. Similarly, if vigorous shrub or tree growth is stopped by removal, or started by planting, near to a building on firm clay subsoil with foundations at a shallow depth, it is most likely that gradual expansion or contraction of the soil will cause damage to the building by differential movement. Significant seasonal volume change,

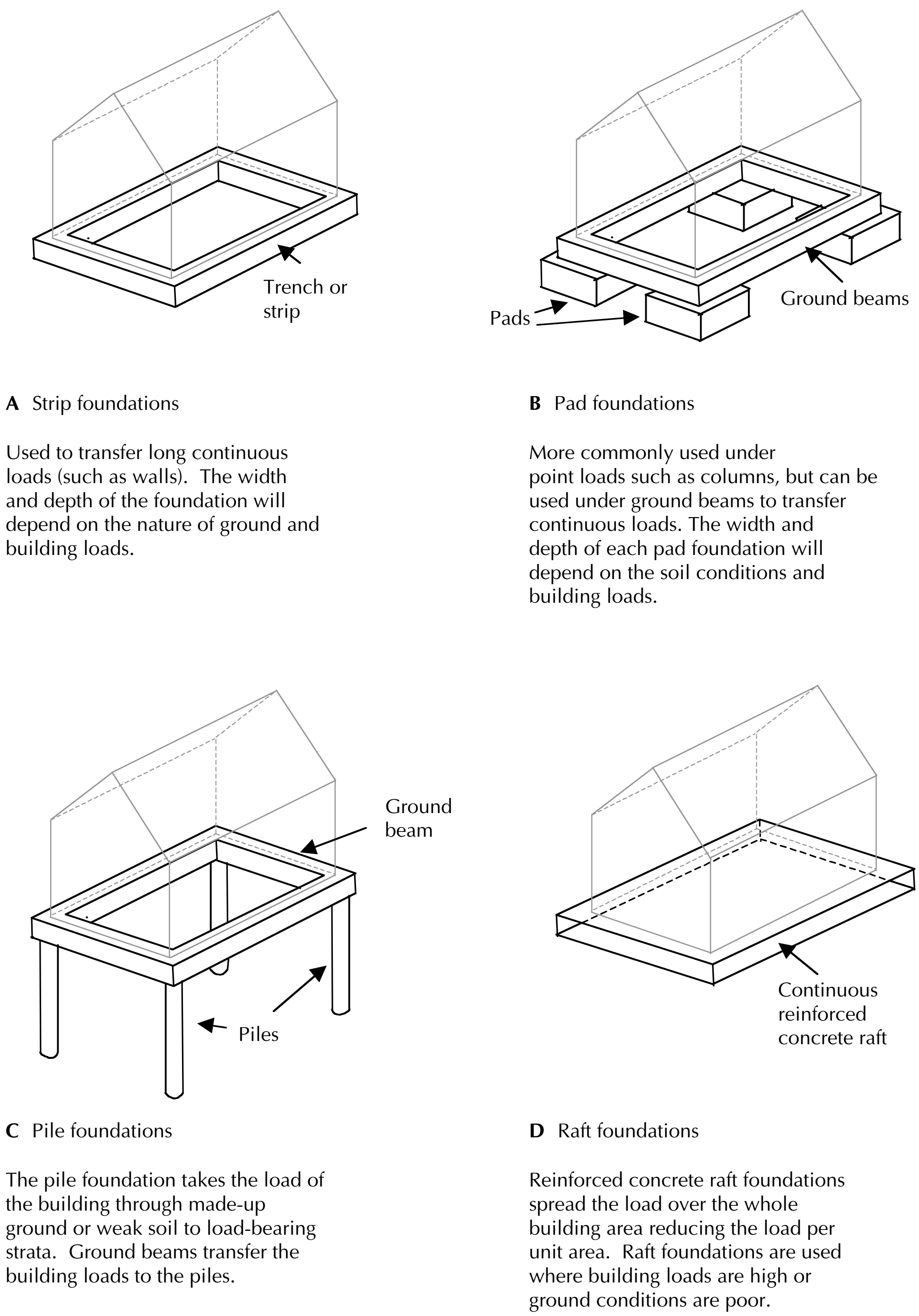
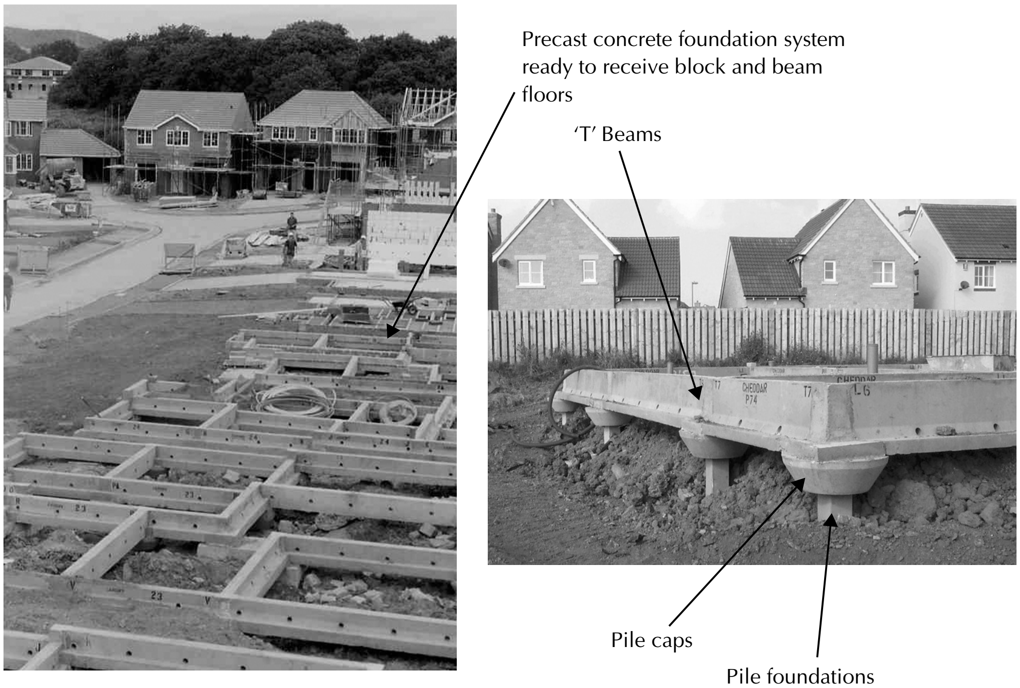


Figure 3.1 Simple schematic of foundation types.



Photograph 3.1 Precast concrete foundations systems (www.roger-bullivant.co.uk).

due to deep-rooted vegetation, may be pronounced during periods of drought and heavy continuous rainfall.

The most economical and effective foundation for low rise buildings on shrinkable clays close to deep-rooted vegetation is a traditional system of short-bored piles and ground beams (Figure 3.1C) or the precast piles and beams such as those shown in Figure 3.2, Photograph 3.1. The piles should be taken down to a depth below which vegetation roots will not cause significant volume changes in the subsoil. Single deep-rooted vegetation such as shrubs and trees as close as their mature height to buildings, and groups of shrubs and trees one-and-a-half times their mature height to buildings, can affect foundations on shrinkable clay subsoils. When planting new trees and shrubs close to buildings proprietary root limiting products should be used (sometimes termed 'root protectors') to help prevent the spread of tree roots and hence provide some protection against damage to building foundations. Expert advice should be sought from a tree surgeon.

Frost heave

Where the water table is high, i.e. near to the surface, soils, such as silts, chalk, fine gritty sands and some lean clays may expand when frozen. This expansion is due to crystals of ice forming and expanding in the soil and so causing frost heave. In the UK, groundwater near the surface rarely freezes at depths of more than 0.5 m, but in exposed positions on open ground during frost it may freeze up to a depth of 1 m. For unheated buildings and heated buildings with insulated ground floors, a foundation depth of 450 mm is generally sufficient against the possibility of damage by ground movement due to frost heave.

Made up ground

Areas of made up ground are often used for buildings as the demand for new buildings increases. Because of the varied nature of the materials tipped to fill and raise ground levels and the uncertainty of the bearing capacity of the fill, conventional foundations may be unsatisfactory and investigation is required to establish the most suitable foundation design. The bearing ground may be some distance below the surface level of the made up ground and to excavate for conventional strip foundations would be grossly uneconomic. A solution is the use of piers (piles) on isolated pad foundations supporting reinforced concrete ground beams on which walls are raised, as illustrated in Figure 3.1C.

Unstable ground

There are extensive areas of ground where mining and excavations for coal, chalk, sand and gravel may have made the ground unstable. Where such works have previously existed the ground and building foundations may well be subject to periodic, unpredictable subsidence. Specialist advice should always be sought to establish the extent of previous workings and the most appropriate method of designing foundations for such situations.

Where it is known that ground may be unstable and there is no ready means of predicting the possibility of mass movement of the subsoil and it is expedient to build, a solution is to use some form of reinforced concrete raft under the whole of the buildings, as illustrated in Figure 3.1D. The concrete raft, which is cast on or just below the surface, is designed to spread the load of the building over the whole of the underside of the raft so that, in a sense, the raft floats on the surface. Alternatively, if there is good loadbearing strata, but they are some metres below the surface, pile foundations can be used.

Precast pile and beam foundation systems

Planning requirements that restrict the removal of trees and encourage building on brownfield sites have resulted in increased use of pile foundations for domestic developments. Precast concrete foundations are often used to overcome difficult ground conditions, problems caused by vegetation or where the speed of construction is important. 'Fast track' pile foundations systems have been developed that are suitable for both timber-framed and traditional masonry construction (Figure 3.2). The general trend towards mechanised installation of foundation systems helps to remove the risks associated with working in deep excavations, workers coming into contact with wet concrete and manual handling of heavy materials.

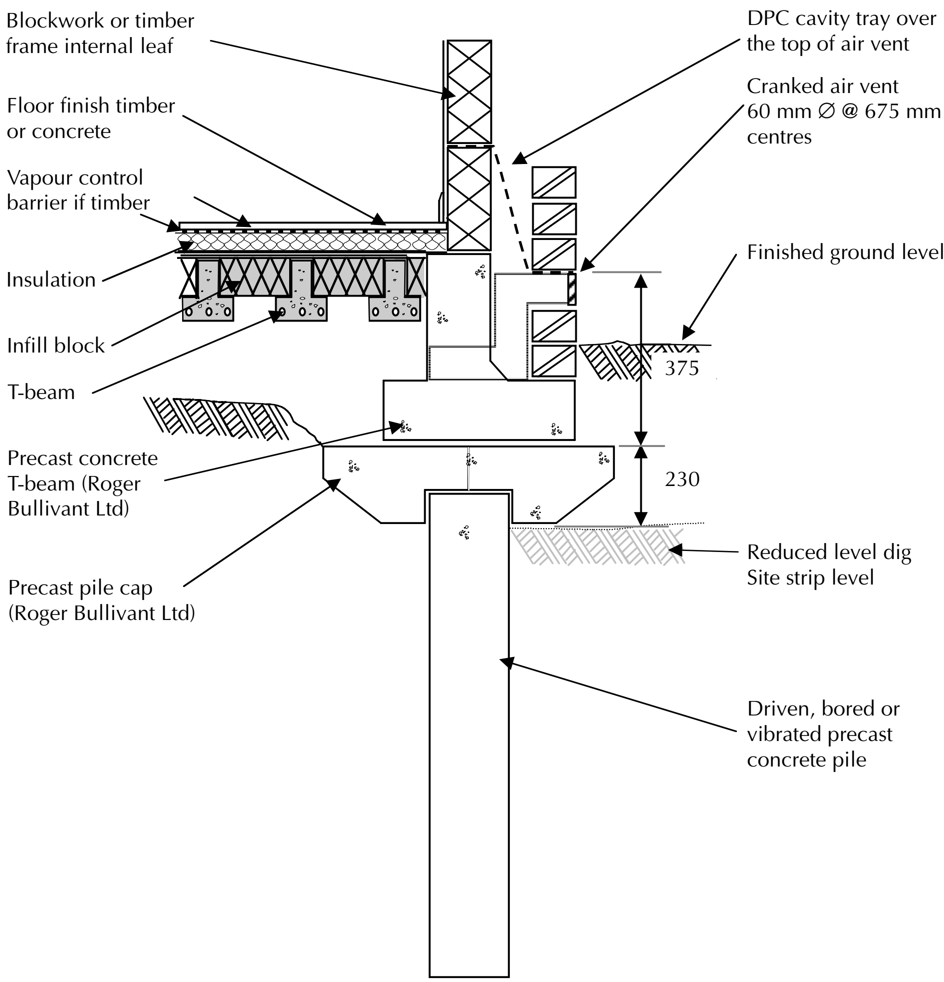


Figure 3.2 Precast concrete foundation system (adapted from www.roger-bullivant.co.uk)

Precast piles can be installed by a top driven hydraulic hammer. Once the correct resistance is achieved, the piles can be cropped to the correct level so that the pile caps and T beams can be quickly installed. Other types of pile may be used, according to ground conditions. These could be: driven steel, continuous flight auger (CFA) or a unique displacement auger pile (CHD).

3.4 Foundation construction

The move to closely regulated systems has resulted in the use of foundations that are less prone to problems than some earlier methods of construction.

One negative effect of this standardised approach is that some foundations may be over-designed for the loads they carry, either to avoid any possibility of foundation failure or simply through the application of inappropriate foundations for a particular building type. For example, it is not uncommon for timber-framed buildings to be built off foundations designed for heavier loadbearing masonry construction, essentially a lack of thought resulting in wasted materials and unnecessary expense.

There are a number of familiar approaches to foundation construction, from strip foundations, piles and rafts as described below (Figure 3.3), all of which are constructed of concrete.

Concrete

Concrete is the name given to a mixture of particles of sand and gravel, the aggregate, bound together with cement, the matrix. Fine aggregate is natural sand, which has been washed and sieved to remove particles larger than 5 mm, and coarse aggregate is gravel that has been crushed, washed and sieved so that the particles vary from 5 mm up to 50 mm in size. The fine and coarse aggregate are delivered separately. By combining them in the correct proportions, a concrete with very few voids or spaces in it can be made that produces a strong concrete.

The cement most used is ordinary Portland cement. It is manufactured by heating a mixture of finely powdered clay and limestone with water to a temperature of about 1200°C, at which the lime and clay fuse to form a clinker. This clinker is ground with the addition of a little gypsum to a fine powder of cement. Cement powder reacts with water and its composition gradually changes; the particles of cement bind together and adhere strongly to materials with which they are mixed. Cement hardens gradually after it is mixed with water. Some thirty minutes to an hour after mixing with water the cement is no longer plastic and it is said that the initial set has occurred. About 10 hours after mixing with water, the cement has solidified and it increasingly hardens to a dense solid mass after 7 days.

Water–cement ratio

The materials used for making concrete are mixed with water for two reasons: first to cause the reaction between cement and water, which results in the cement acting as a binding agent and, secondly, to make the material sufficiently plastic to be easily placed in position. The ratio of water to cement used in concrete affects its ultimate strength. If too little water is used the concrete is so stiff that it cannot be compacted and if too much water is used the concrete does not develop full strength. Very little water is required to ensure that a full chemical reaction takes place within the concrete mix. Any excess water will not be used and will leave very small voids within the concrete when the unused water eventually evaporates away. The water added must be sufficient to

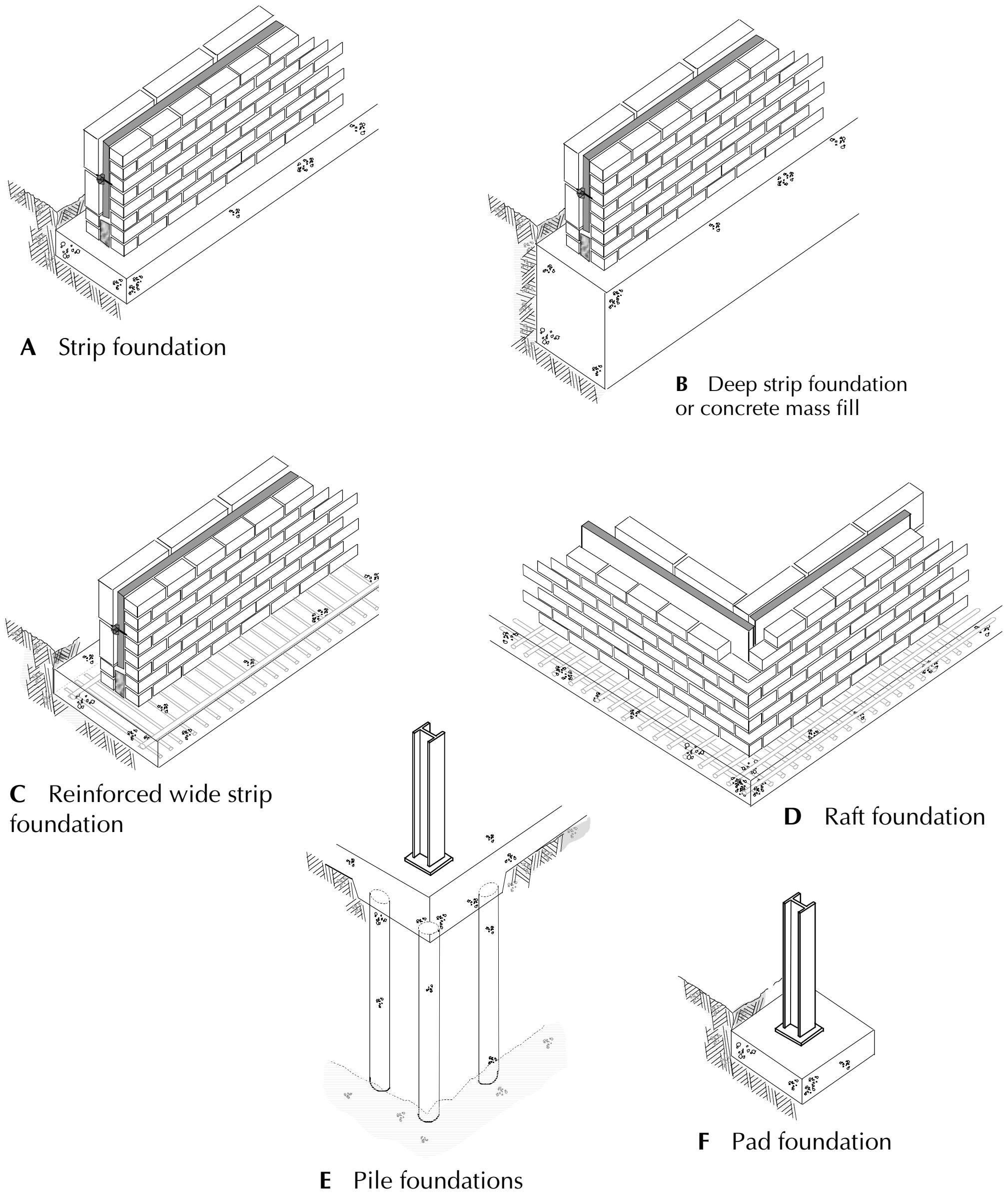


Figure 3.3 Foundation types.

allow the chemical reaction to take place and enable the concrete to be worked (poured or vibrated) into place. The amount of water required to make concrete sufficiently plastic (workable) depends on the position in which the concrete is to be placed. Plasticisers are added to the concrete mixture and enable the concrete to be more workable and fluid without increasing the quantities of water used. Using plasticisers keeps the strength of the concrete high without increasing the quantity of cement.

Concrete mixes

The materials used in reinforced concrete are commonly weighed and mixed in large concrete mixers. It is not economical for builders to employ expensive concrete mixing machinery for small buildings and the concrete for foundations, floors and lintels is usually delivered to site ready mixed, except for small batches that are mixed by hand or in a portable mixer.

British Standard 5328: specifying concrete, including ready-mixed concrete, gives a range of mixes. One range of concrete mixes in the Standard, ordinary prescribed mixes, is suited to general building work such as foundations and floors. These prescribed mixes should be used in place of the traditional nominal volume mixes such as 1:3:6 cement, fine and coarse aggregate by volume, which have been used in the past. The prescribed mixes, specified by dry weight of aggregate, used with 100 kg of cement, provide a more accurate method of measuring the proportion of cement to aggregate and, as they are measured against the dry weight of aggregate, allow for close control of the water content and therefore the strength of the concrete.

Prescribed mixes are designated by the letters and numbers C7.5P, C10P, C15P, C20P, C25P and C30P; the letter C stands for 'compressive', the letter P for 'prescribed' and the number indicates the 28-day characteristic cube crushing strength in newtons per square millimetre (N/mm^2) that the concrete is expected to attain. The prescribed mix specifies the proportions of the mix to give an indication of the strength of the concrete sufficient for most building purposes, other than designed reinforced concrete work.

Table 3.1 equates the old nominal volumetric mixes of cement and aggregate with the prescribed mixes and indicates the uses for these mixes.

Ready-mixed concrete

Ready-mixed concrete plants are common and are able to supply to all but the most isolated building sites. These plants prepare carefully controlled concrete mixes, which are delivered to site by lorries on which the concrete is churned to

Table 3.1 Concrete mixes

Nominal volume mix	BS 5328 Standard mixes	Uses
1:8 all-in 1:3:6	ST1	Foundations
1:3:6 1:2:4	ST2 ST3	Site concrete
1:1$\frac{1}{2}$:3	ST4	Site concrete reinforced

delay setting. The standard lorries, which hold the concrete mixers, deliver up to 6 m^3 loads; however, some plants do have 8 m^3 lorries, and smaller lorries of 4 m^3 and less for occasional small loads.

To order ready-mixed concrete it is necessary to specify only the prescribed mix, for example C10P, the cement, type and size of aggregate and workability. The workability required will depend on the situation where the concrete is to be used. Very stiff mixes (low workability) are used to bed kerb stones, concrete flags, road gullies and slabs. If highly workable and fluid mixes were used in these situations the precast concrete units would simply sink through the concrete. However, when a stiff mix is used, the precast or stone units can be easily bedded at the correct level. If concrete needs to be poured into deep formwork, which has considerable reinforcement, the concrete needs to be sufficiently fluid to pass through the gaps in the reinforcement to the bottom of the formwork.

Soluble sulphates

There are water soluble sulphates in some soils, such as plastic clay, which react with ordinary cement and in time will weaken concrete. Sulphate-resistant cements are more resistant to the destructive action of sulphates. Sulphate-resisting Portland cement has a reduced content of aluminates that combine with soluble sulphates in some soils and is used for concrete in contact with those soils.

Strip foundations

Strip foundations consist of a continuous strip, usually of steel reinforced concrete, formed centrally under loadbearing walls. This continuous strip serves as a level base on which the wall is built and is of such a width as is necessary to spread the load on the foundations to an area of subsoil capable of supporting the load without undue compaction. The bearing capacity of the soil should be greater than the loads imposed by the buildings foundation.

Figure 3.4 illustrates a strip foundation. The continuous strip of concrete is spread in the trenches excavated down to an undisturbed level of compact soil. The strip of concrete may well need to be no wider than the thickness of the wall. In practice the concrete strip will generally be wider than the thickness of the wall for the convenience of covering the whole width of the trench and to provide a wide enough level base for bricklaying below ground. A continuous strip foundation of concrete is the most economic form of foundation for small buildings on compact soils. (See Photograph 3.2.)

The width of a concrete strip foundation depends on the bearing capacity of the subsoil and the load on the foundations: the greater the bearing capacity of the subsoil, the less the width of the foundation and vice versa. Table 3.2 (from Approved Document A) sets out the recommended minimum width of concrete strip foundations related to six specified categories of subsoil and calculated total loads on foundations.

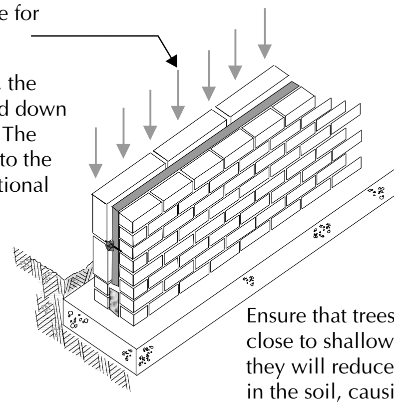


Figure 3.4 Strip foundation.

The dimensions given in Table 3.2 are indicative of what might be acceptable in the conditions specified rather than absolutes to be accepted regardless of the conditions prevailing on individual sites. Figure 3.5A and B illustrate the important dimensions.

The strip foundation for a cavity external wall and a solid internal, load bearing wall illustrated in Figure 3.6 would be similar to the width recommended in the Approved Documents for a firm clay subsoil when the load on the foundations is no more than 50 kN/linear metre. In practice the linear load on the foundation of a house would be appreciably less than 50 kN/linear metre and the foundation may well be made wider than the minimum requirement for the convenience of filling a wider trench with concrete, due to the width of the excavator's bucket, or for the convenience of laying brick below ground, allowing adequate working space.

If the thickness of a concrete strip foundation (without steel reinforcement) were appreciably less than its projection each side of a wall, the concrete might fail through the weight of the wall causing a 45° shear crack as illustrated in Figure 3.7. If this occurred the bearing surface of the foundation on the ground would be reduced to less than that necessary for stability. Concrete has few tensile properties and is only good in compression. In Figure 3.7 where the load is place directly on top of the concrete foundation and compressed between the ground, the foundation remains stable. However, the concrete outside the 45° angle (where compressive forces are distributed) experiences some tension as the reaction of the ground attempts to lever the foundation upwards, thus the foundation would fail.

Stepping strip foundations

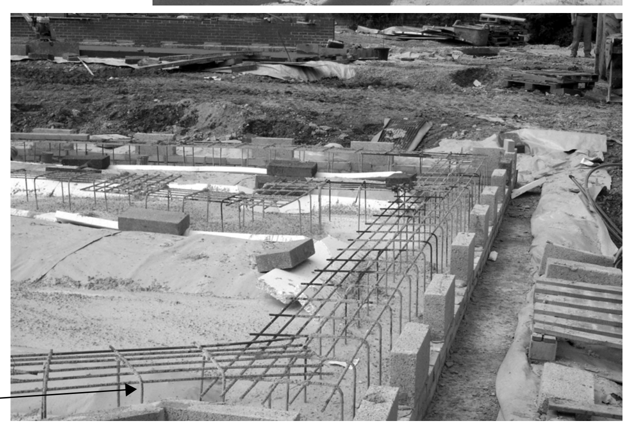
Where strip foundations are used on sloping sites it may be necessary to step the foundation (Figure 3.8). In order to step the foundation, the full thickness

The trenches for the foundations are excavated.

A continuous membrane is then laid over the whole area of the building. Traditionally the membrane would be used to prevent the penetration of damp into the building, nowadays such barriers are often used to prevent gases as well as moisture entering into the dwelling. The membrane or damp proof membrane (DPM) acts as a barrier separating the building from the ground.

The reinforcement for the trench foundation (ground beam) is then positioned in line and at the correct level. The main trenches and beams will be positioned under loadbearing walls.

Spacers are used to hold the reinforcement off the ground. This allows concrete to go underneath the reinforcement ensuring adequate cover all around the reinforcement.



Ensuring the steel reinforcement is correctly positioned within the concrete will mean that they can bond together. The matrix formed between the reinforcement and concrete allows the foundation to deal with both the compressive and tensile forces. If the steel did not bond with the concrete the forces would not be able to transfer from one material to the other and the foundation would fail.

The trench foundations are poured up to the underside of the floor slab. The internal blockwork wall can then be built up to floor level; this will act as edge support when the concrete floor is poured.

Part of the ground beam reinforcement remains uncovered during this stage. This will eventually be cast into the floor forming a complete reinforced concrete ground beam.

Light steel mesh reinforcement will be placed over the whole of the floor slab. This will prevent the concrete slab cracking if the ground between the ground beams settles.

Finally, the floor slab is cast and levelled off and the external cavity wall is built up to DPC (damp proof course) level.

Photograph 3.2 Trenches and ground beams. Source: www.leedsmet.ac.uk/teaching/vsite

Table 3.2 Minimum width of strip foundations

Types of subsoil	Condition of subsoil	Field test applicable	Total load of load-bearing walling – not more than (kN/linear metre)					
			20	30	40	50	60	70
			Minimum width of strip foundation (mm)					
Rock	Not inferior to sandstone, limestone or firm chalk	Requires at least a mechanically operated pick for excavation	Equal to the width of the wall					
Gravel Sand	Compact Compact	Requires pick for excavation. Wooden peg 50 mm square cross-section hard to drive in beyond 150 mm	250	300	400	500	600	650
Clay Sandy clay	Stiff Stiff	Cannot be moulded with the fingers and requires pick for removal	250	300	400	500	600	650
Clay Sandy clay	Firm Firm	Can be moulded by substantial pressure with fingers, can be excavated with a spade	300	350	450	600	750	850
Sand Silty sand Clayey sand	Loose Loose Loose	Can be excavated with a spade. Wooden peg 50 mm × 50 mm cross-section easily driven	400	600	When the loads exceed 30 kN/linear metre in such weak soil conditions, the widths of strip foundations are not specified in the Building Regulations. Alternative types of foundation would be more suitable.			
Silt Clay Sandy clay Silty clay	Soft Soft Soft Soft	Fairly easy to mould with fingers. Easy to excavate	450	650				
Silt Clay Sandy clay Silty clay	Very soft Very soft Very soft Very soft	Extrudes between fingers when squeezed	600	850				

Source: Approved Document A, 2000

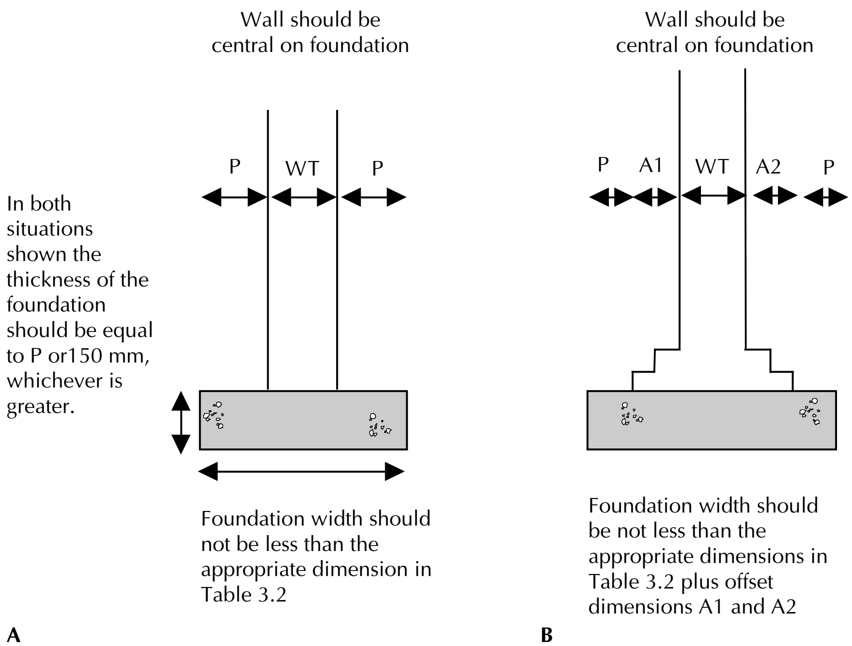


Figure 3.5 A & B Foundation dimensions (adapted from Approved Document A).

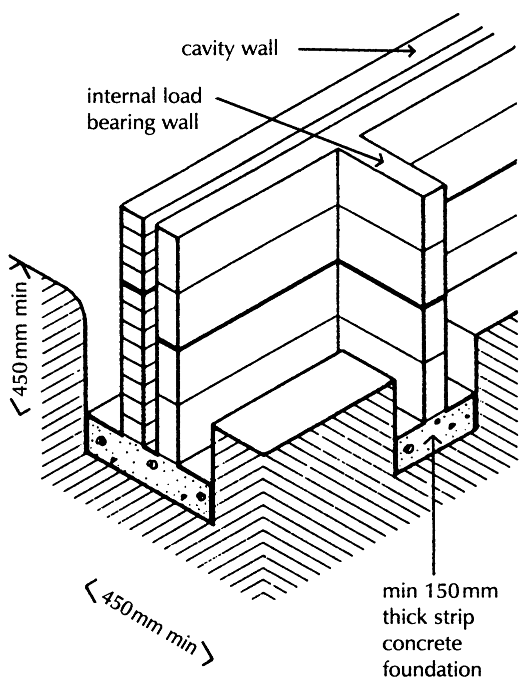


Figure 3.6 Strip foundation.

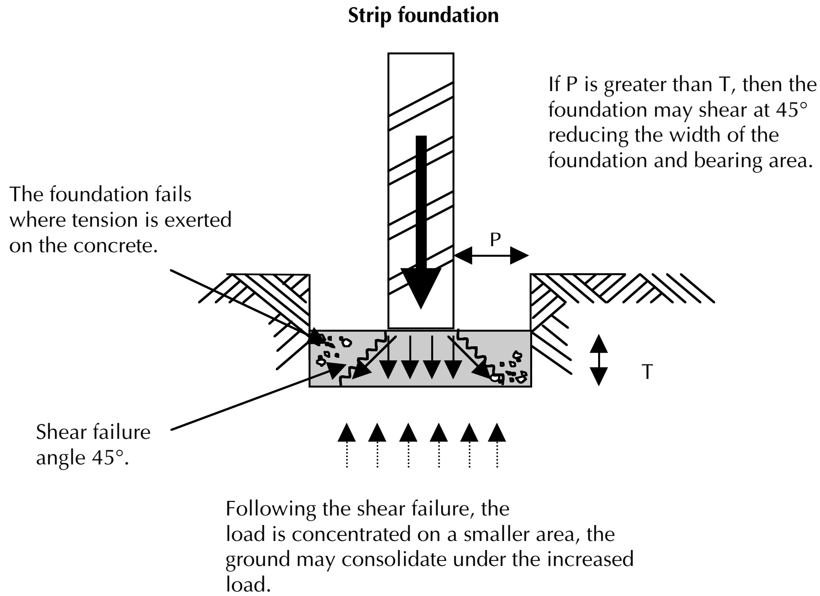


Figure 3.7 Shear failure in a strip foundation.

of the upper foundation should overlap twice the height of the step (thickness of upper foundation), or 300 mm, whichever is greater.

When stepping foundations consideration should also be given to the brickwork and blockwork that will be built on top of the foundation. The brickwork and blockwork should tie in at the step to avoid the need for cutting bricks and blocks and also to avoid the possibility of reducing the stability of the wall, as illustrated in Figure 3.9.

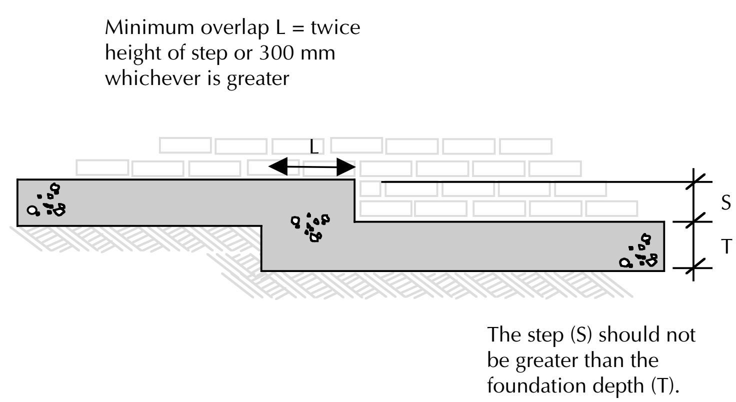


Figure 3.8 Stepped strip foundations.

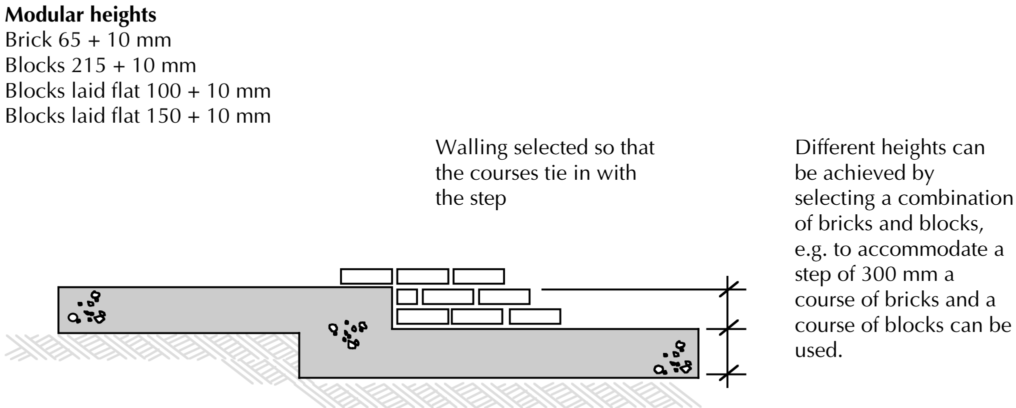


Figure 3.9 Brick coursing to stepped foundations.

Wide strip foundation

Distributing the load over a larger area reduces the load per unit area on the ground. Strip foundations on subsoils with poor bearing capacity, such as soft sandy clays, may need to be considerably wider than traditional (narrow) strip foundations. However, to keep increasing the width and depth of the concrete ensuring that the foundation does not shear makes the process uneconomical. The alternative is to form a strip of steel-reinforced concrete, illustrated in Figures 3.10 and 3.11.

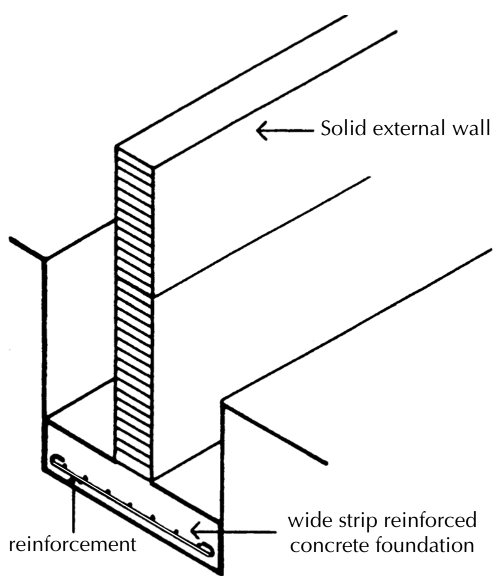


Figure 3.10 Wide strip foundation.

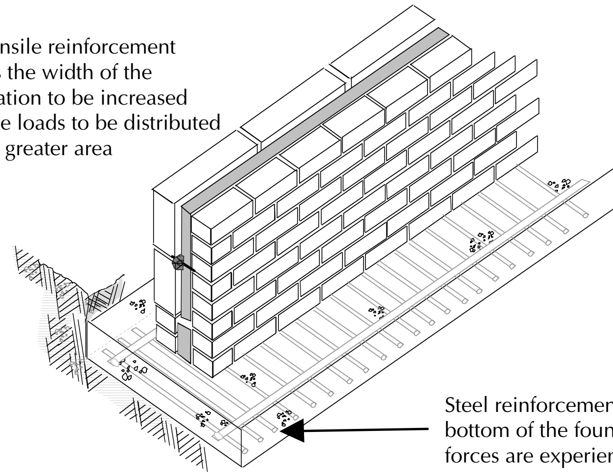


Figure 3.11 Steel reinforced wide strip foundation.

Concrete is strong in compression, but is weak in tension. The effect of the downward pressure of the wall on the middle of the foundation and the opposing force of the ground spread across the base of the foundation attempts to bend the foundation upwards; this places the top of the foundation in compression and the base of the foundation in tension.

These opposing pressures will tend to cause the shear cracking illustrated in Figure 3.12. To add tensile properties to the foundation steel, reinforcing bars are cast in the lower edge where tension will occur. There has to be a

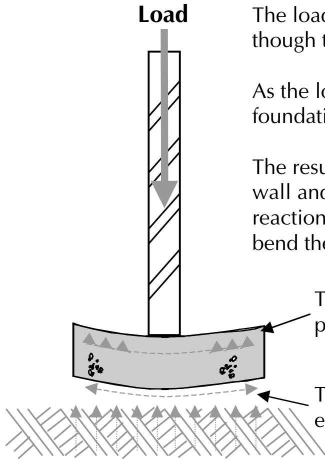


Figure 3.12 Distribution of forces in strip foundations.

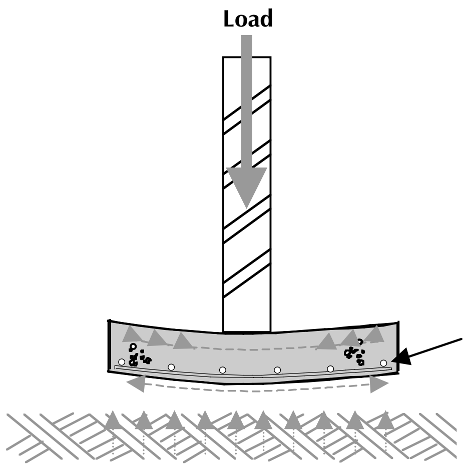


Figure 3.13 Accommodating tensile forces within strip foundations.

sufficient cover of concrete below the steel reinforcing rods to ensure a good bond between the concrete and steel and to protect the steel from corrosion. The steel and concrete make up a composite material that can resist both tensile and compressive forces. It is essential that the steel is placed where the tensile forces occur, see Figure 3.13.

Narrow strip (trench fill or deep strip) foundation

Stiff clay subsoils have good bearing strength and are subject to seasonal volume change. Because of seasonal changes and the withdrawal of moisture by deep rooted vegetation (such as shrubs and trees) it is practice to adopt a foundation depth of at least 0.9 m to provide a stable foundation. Although the base of a deep strip foundation will go to a depth where the clay soil is unaffected by seasonal changes in moisture content, the soil at the external face of the foundation will still expand and contract as it becomes saturated and dries out. To prevent lateral pressure being applied to the side of the foundation, a 50 mm thick compressible sheet material may be used (Figure 3.14).

Because of the good bearing capacity of the clay, the foundation may need to be little wider than the thickness of the wall to be supported. Trenches are usually formed by using mechanical excavators, thus the width of the trench is determined by the width of the excavator bucket available, which should not be less than the minimum required width of foundation. The trench is filled with concrete as soon as possible so that the sides of the trench do not fall in and the exposed clay bed does not dry out and shrink (as illustrated in Figure 3.15A). Where the trench is particularly wide and it is uneconomical to fill the whole trench with concrete it is common practice to use trench blocks. The trench blocks are laid flat and are often the full width of the walling above them (as illustrated in Figure 3.15B).

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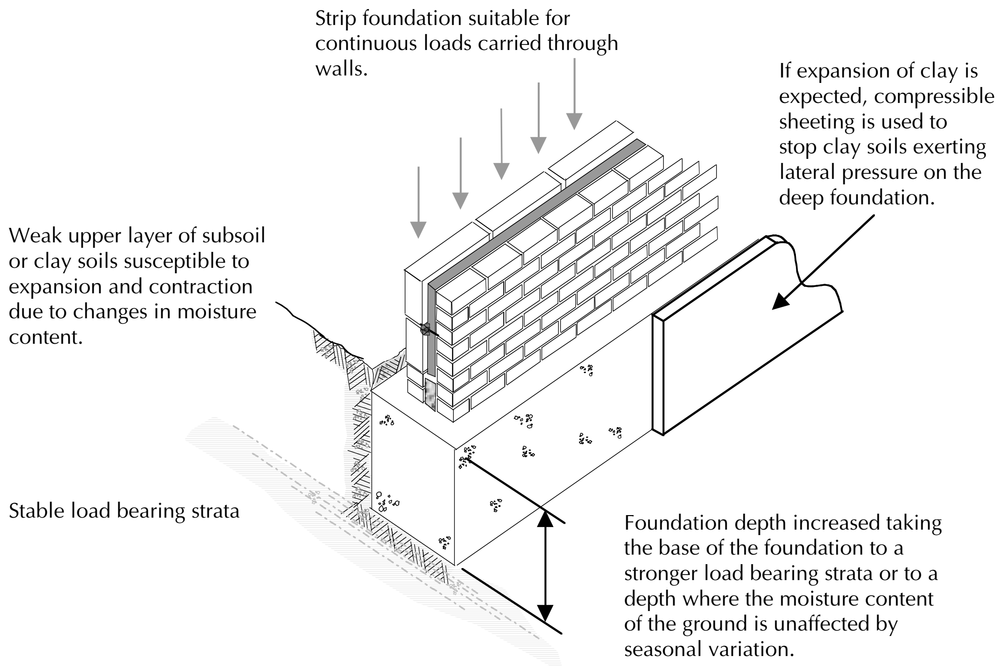


Figure 3.14 Deep strip or mass fill strip foundation.

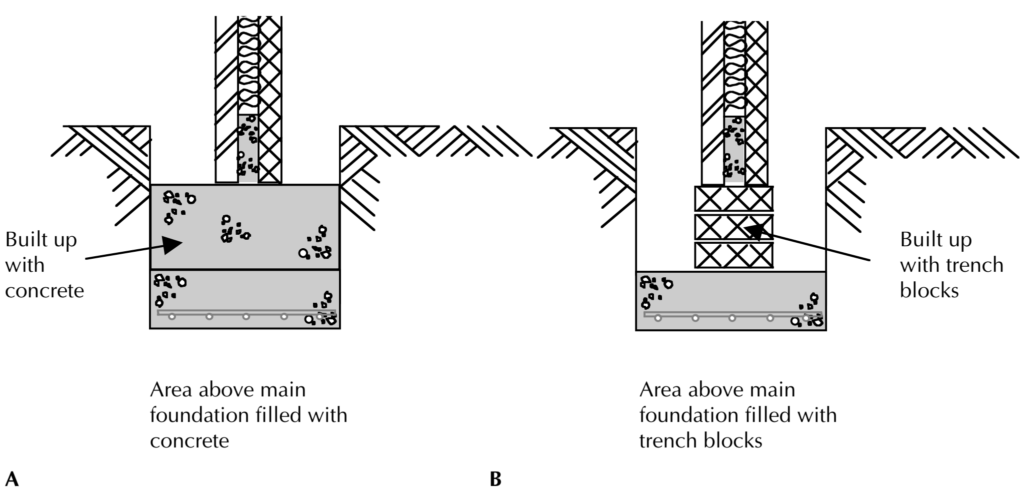


Figure 3.15 A & B Use of trench fill and trench blocks in strip foundations.

Short bored pile foundations

Where the subsoil is of firm, shrinkable clay, which is subject to volume change due to deep rooted vegetation for some depth below the surface and where the subsoil is of soft, or uncertain bearing capacity for a few metres below the surface, it may be economic and satisfactory to use a system of short bored piles as a foundation (Figure 3.16). Piles are concrete columns, which are either precast and driven (hammered) into the ground or cast in holes that are augured (drilled) into the ground down to a level of a firm, stable stratum of subsoil (Figure 3.17).

The piles that are excavated to a depth of 4 m below the surface are termed short bore, which refers to the comparatively short length of the piles as compared to the much longer piles used for larger buildings. Short bored piles are generally from 2 to 4 m long and from 250 to 350 mm diameter.

Holes are augered into the ground by machine. An auger is a form of drill comprising a rotating shaft with cutting blades that screw into the ground. The soil is either withdrawn and lifted to the surface as the shaft rotates or, with small augers, once the auger has cut into the ground it is withdrawn and the soil removed from the blades. The advantage of this system of augered holes is that samples of the subsoil are withdrawn, from which the nature and bearing capacity of the subsoil may be assessed. The piles may be formed of concrete or, more usually, a light steel cage of reinforcement is lowered into the hole and concrete poured or pumped into the hole and compacted

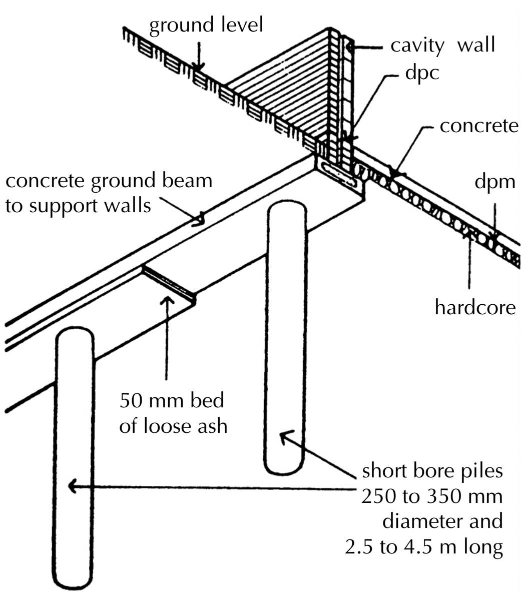


Figure 3.16 Short bored pile foundation (worm's eye view).

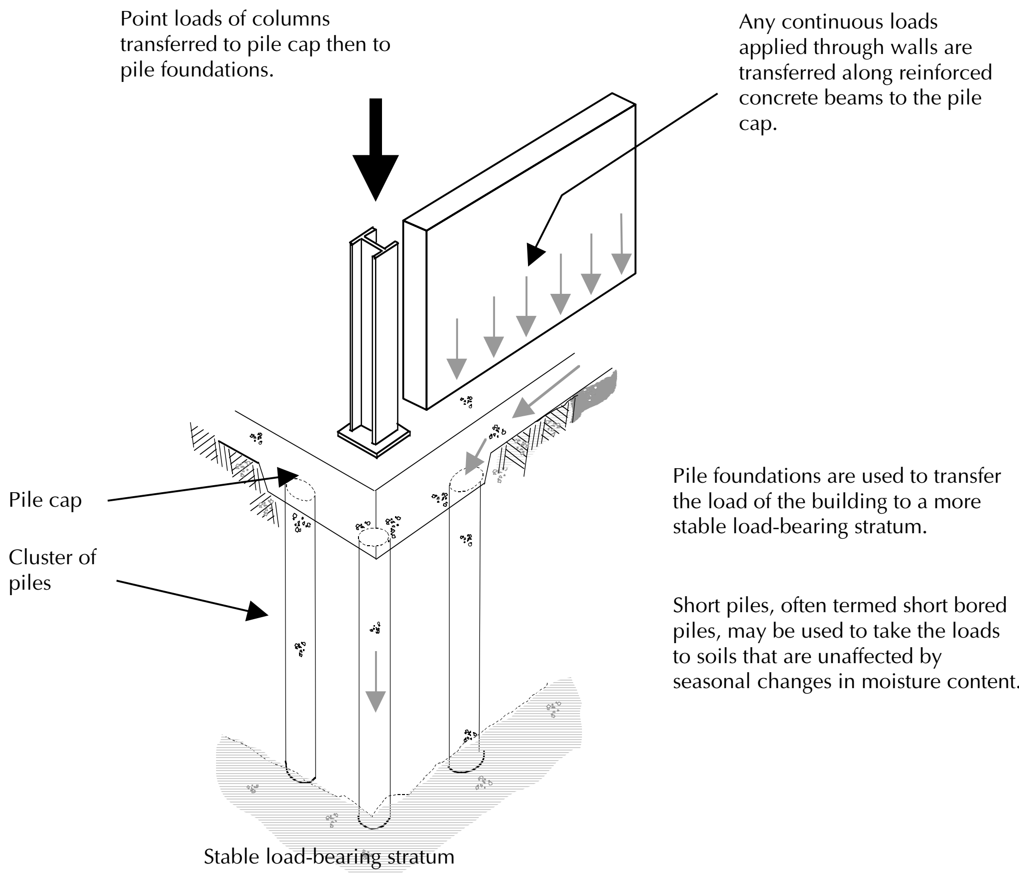


Figure 3.17 Pile foundations.

to form a pile foundation. The piles are cast underneath the corners and intersection of loadbearing walls and at regular intervals between to reduce the span and depth of the reinforced ground beam, which transfers the wall and building loads to the foundation. A reinforced concrete ground beam is then cast over the piles as illustrated in Figure 3.18. The spacing of the piles depends on the loads to be supported and on economic sections of ground beam, see Figure 3.18.

Pad foundations

Pad foundations can be used to carry point loads or can be designed so that the loads of the walls and the buildings are transferred through ground beams that rest on pad foundations. The pad foundations transfer the loads to a lower

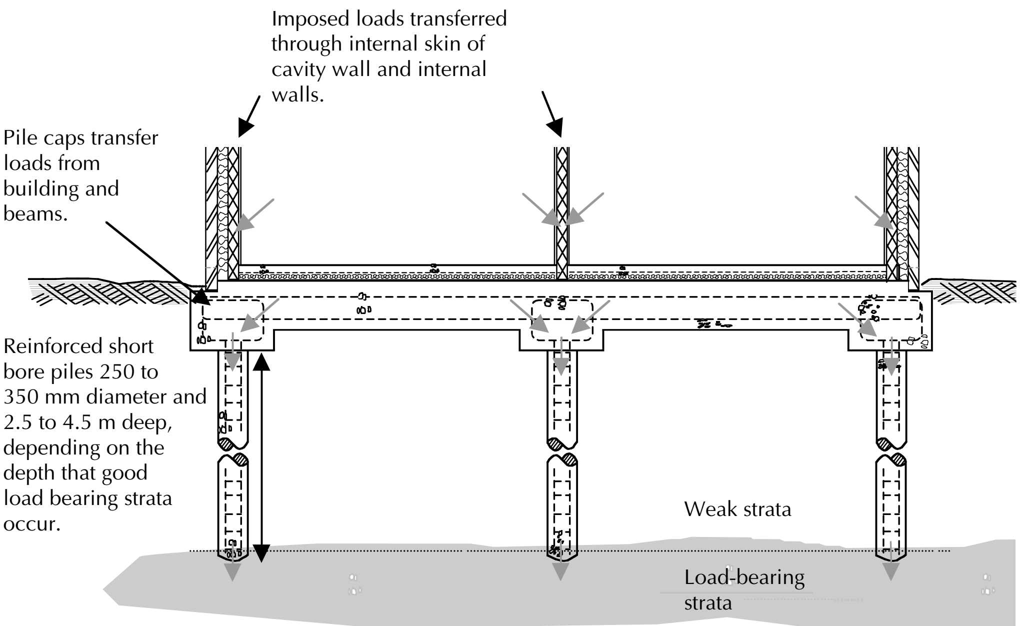


Figure 3.18 Section illustrating pile foundations.

level where soil of sufficient loadbearing strata exists (Figure 3.19). The width of a pad foundation can be increased to distribute the loads over a greater area, thus reducing the pressure on the ground. Photograph 3.3 shows the excavation sequence of pad foundations and ground beams.

On made up ground and ground with poor bearing capacity where a firm, natural bed of strata, for example, gravel or sand is some few metres below the surface, it may be economic to excavate for isolated piers of brick or concrete to support the load of buildings. The piers will be built at the angles, intersection of walls and under the more heavily loaded wall such as that between windows up the height of the building.

Pits are excavated down to the necessary level, the sides of the excavation temporarily supported and isolated pads of concrete are cast in the bottom of the pits. Brick piers or reinforced concrete piers are built or cast on the pad foundations up to the underside of the reinforced concrete beams that support walls as illustrated in Figure 3.20. The ground beams or foundation beams may be just below or at ground level, the walls being raised off the beams.

The advantage of this system of foundation is that pockets of tipped stone or brick and concrete rubble that would obstruct bored piling may be removed as the pits are excavated and that the nature of the subsoil may be examined

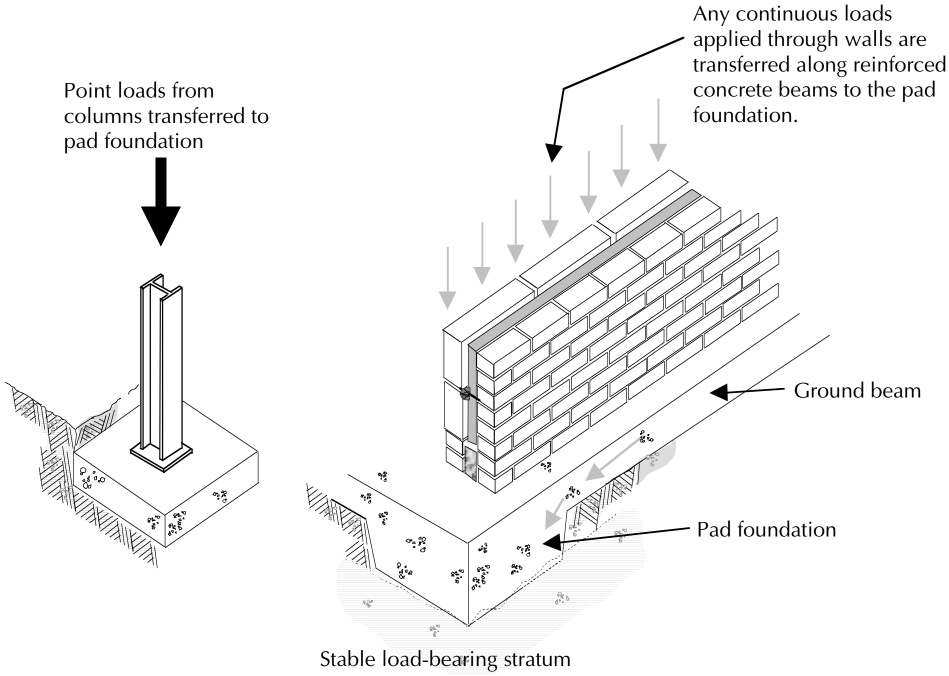


Figure 3.19 Pad foundations.

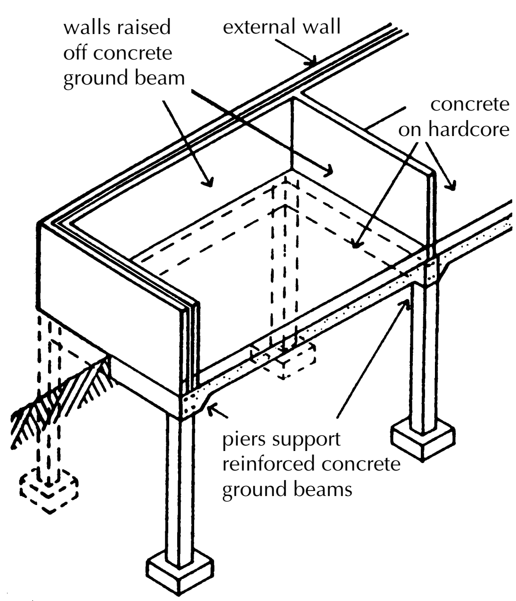
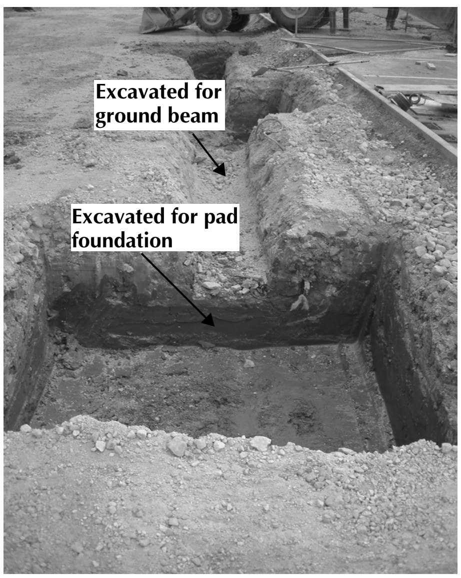


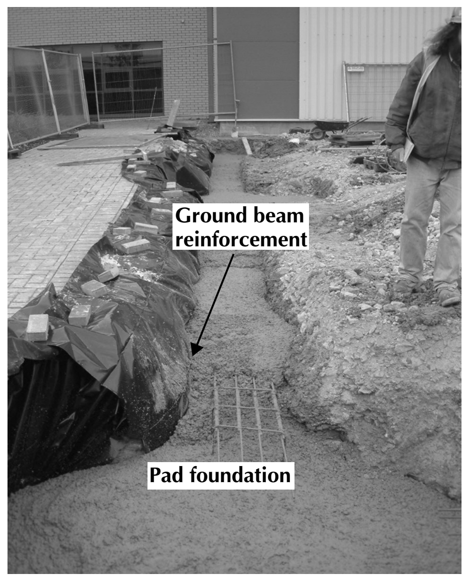
Figure 3.20 Pad foundations.

A The foundation is marked out and excavated to the correct level. The machine operator attempts to keep the sides of the excavation as true and square as possible.

B This pad foundation has been excavated down to good loadbearing strata. The bottom of the foundation is clean and ready for inspection by the building control officer.



C Once one pad foundation is complete, the ground beam, which spans between the pad foundations, is excavated, then the next pad foundation is dug out.



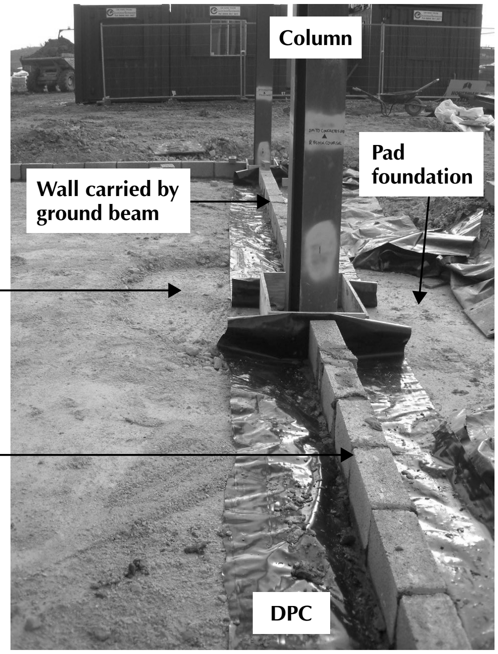
D The reinforcement is placed in the ground beam foundation, positioned correctly and then the concrete is poured to the correct level. The concrete should be vibrated to remove air bubbles.

Photograph 3.3 Excavation and casting of pad foundation and ground beam.

Once the foundations have set the building can be constructed on top of them.

The columns are a point load and are positioned and bolted to the pad foundation.

The walls, which span between the columns, rest on the ground beam. The loads from the walls are transferred via the ground beam to the pad foundation.



E The loads from the columns (point loads) and walls (distributed loads) are transferred to the foundations

Photograph 3.3 (*continued*).

as the pits are dug to select a level of sound subsoil. This advantage may well be justification for this labour intensive and costly form of construction.

Raft foundations

A raft foundation consists of a raft of reinforced concrete under the whole of a building. Raft foundations may be used for buildings on compressible ground such as very soft clay, alluvial deposits and compressible fill material where strip, pad or pile foundations would not provide a stable foundation without excessive excavation. The reinforced concrete raft is designed to transmit the load of the building and distribute the load over the whole area under the raft, reducing the load per unit area placed on the ground (Figure 3.21). Distributing the loads in this way causes little, if any, appreciable settlement. The two types of raft foundation commonly used are the flat raft and the wide toe raft.

The flat slab raft is of uniform thickness under the whole of the building and reinforced to spread the loads from the walls uniformly over the under surface to the ground. This type of raft may be used under small buildings such as bungalows and two storey houses where the comparatively small loads on foundations can be spread safely and economically under the rafts. The

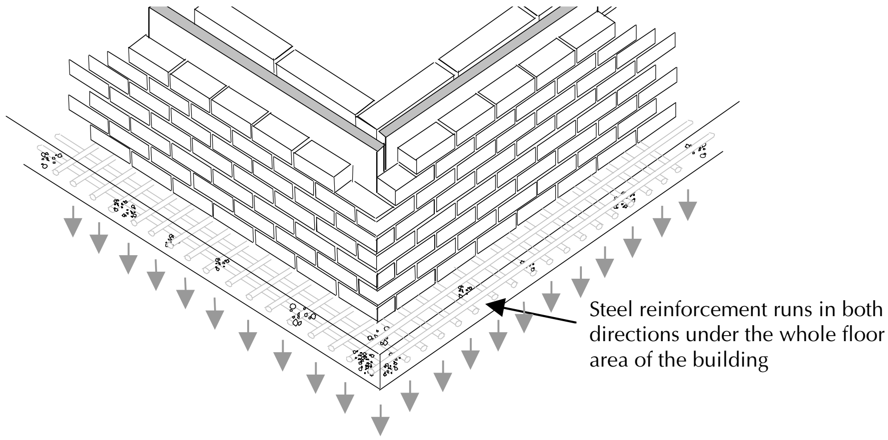


Figure 3.21 Raft foundation.

concrete raft is reinforced top and bottom against both upward and downward bending. The construction sequence is as follows.

(1) Vegetable topsoil is removed.
(2) A blinding layer of concrete 50 mm thick is spread and levelled to provide a level base so that the steel reinforcement cage can be constructed.
(3) Where the raft is not cast directly against the ground, formwork may be required to contain any concrete up-stands.
(4) Once the reinforcement is correctly spaced, and tied together in position, the concrete can be poured, vibrated and levelled.
(5) A waterproof membrane can be positioned either underneath the structural concrete or on top beneath the insulation. Some architects choose to position the damp proof membrane (dpm) on top of the insulation and beneath the finish screed. Traditionally the damp proof membrane (dpm) was placed on top of the blinding; it is now more common for the dpm to sit on top of the insulation (providing the insulation is impermeable). When the dpm is positioned above the insulation it not only prevents groundwater penetration but also reduces the possibility of interstitial condensation forming.
(6) Rigid insulation boards are placed on top of the structural concrete.
(7) Finally a 40 mm sand/cement screed finish is spread and levelled on top of the raft.

When the reinforced concrete raft has dried and developed sufficient strength the walls are raised as illustrated in Figure 3.22. The concrete raft is usually at least 150 mm thick.

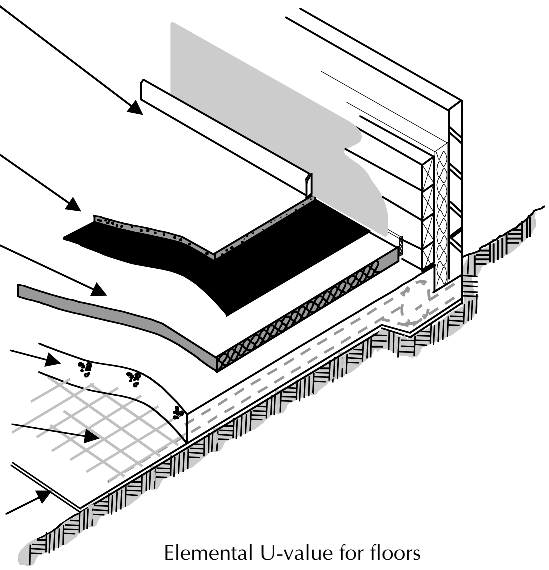


Figure 3.22 Construction of a concrete raft foundation.

A flat slab recommended for building in areas subject to mining subsidence is similar to the flat slab, but cast on a bed of fine granular material 150 mm thick so that the raft is not keyed to the ground and is therefore unaffected by horizontal ground strains. Where the ground has poor compressibility and the loads on the foundations would require a thick, uneconomic flat slab, it is usual to cast the raft as a wide toe raft foundation. The raft is cast with a reinforced concrete, stiffening edge beam from which a reinforced concrete toe extends as a base for the external leaf of a cavity wall as shown in Figures 3.23 and 3.24.

Raft foundation on a sloping site

On sites where the slope of the ground is such that there is an appreciable fall in the surface across the width or length of a building, and a raft foundation is to be used, it is necessary either to cut into the surface or provide additional fill under the building or a combination of both to provide a level base for the raft.

Where the slope is shallow and the design and use of the building allows, a stepped raft may be used down the slope, as illustrated in Figure 3.25. A stepped, wide toe, reinforced concrete raft is formed with the step or steps made at the point of a loadbearing internal wall or at a division wall between

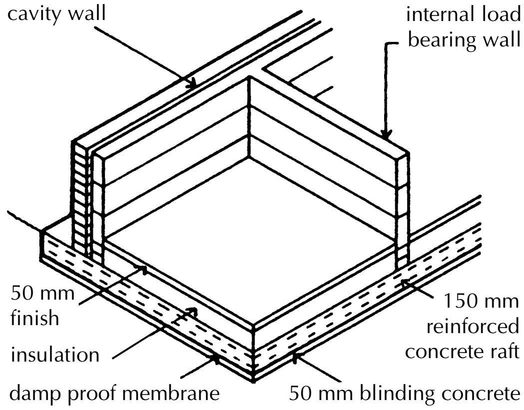


Figure 3.23 Flat slab raft.

compartments. The drains under the raft are to relieve and discharge surface water running down the slope that might otherwise be trapped against steps and promote dampness in the building.

The level raft illustrated in Figure 3.24 is cast on imported granular fill that is spread, consolidated and levelled as a base for the raft. The disadvantage of this is the cost of the additional granular fill and the advantage a level bed of uniform consistency under the raft. As an alternative the system of cut and fill may be used to reduce the volume of imported fill.

Raft foundations are usually formed on ground of soft subsoil or made up ground where the bearing capacity is low or uncertain, to minimise settlement.

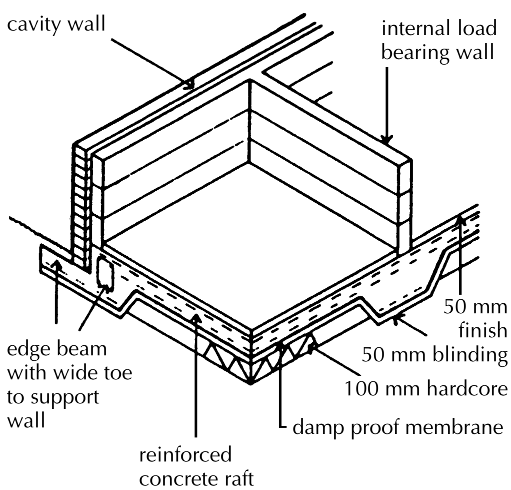


Figure 3.24 Edge beam raft.

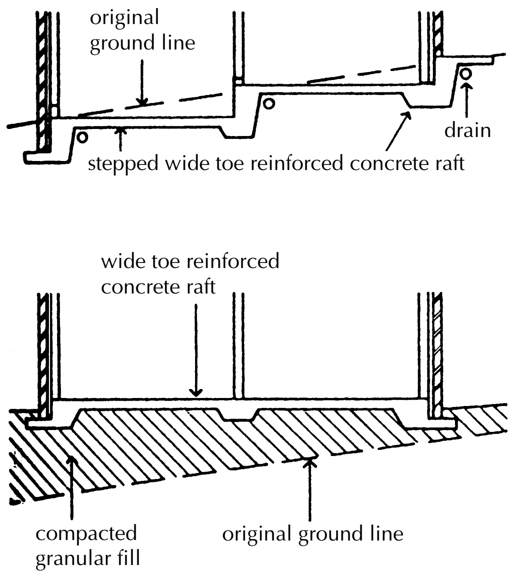


Figure 3.25 Raft on sloping site.

There is some possibility of there being some slight movement of the ground under the building which would fracture drains and other service pipes entering the building through the raft. Service pipes rising through the raft should run through collars, cast in the concrete, which will allow some movement of the raft without fracturing service pipes.

Foundations on sloping sites

The natural surface of ground is rarely level. On sloping sites an initial decision to be made is whether the ground floor is to be above ground at the highest point or partly sunk below ground as illustrated in Figure 3.25. Where the ground floor is to be at or just above ground level at the highest point, it is necessary to import some dry fill material such as hardcore to raise the level of the oversite concrete and floor. This fill will be placed, spread and consolidated up to the external wall once it has been built.

The consolidated fill will impose some horizontal pressure on the wall. To make sure that the stability of the wall is adequate to withstand this lateral pressure it is recommended practice that the thickness of the wall should be at least a quarter of the height of the fill bearing on it as illustrated in Figure 3.27A and B. The thickness of a cavity wall is taken as the combined thickness of the two leaves unless the cavity is filled with concrete when the overall thickness is taken.

To reduce the amount of fill necessary under solid floors on sloping sites a system of cut and fill may be used as illustrated in Figure 3.26. The disadvantage

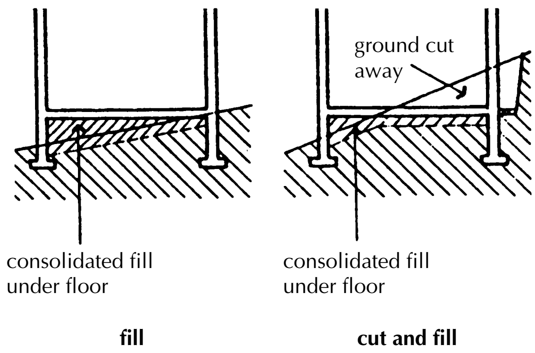


Figure 3.26 Fill and cut and fill.

of this arrangement is that the ground floor is below ground level at the highest point and it is necessary to form an excavated dry area to collect and drain surface water that would otherwise run up to the wall and cause problems of dampness. To reduce the depth of excavation and the foundations a stepped foundation is used as illustrated in Figure 3.28.

Figure 3.29 is an illustration of the stepped foundation for a small building on a sloping site where the subsoil is reasonably compact near the surface and will not be affected by volume changes. The foundation is stepped up the slope to minimise excavation and walling below ground. The foundation is stepped

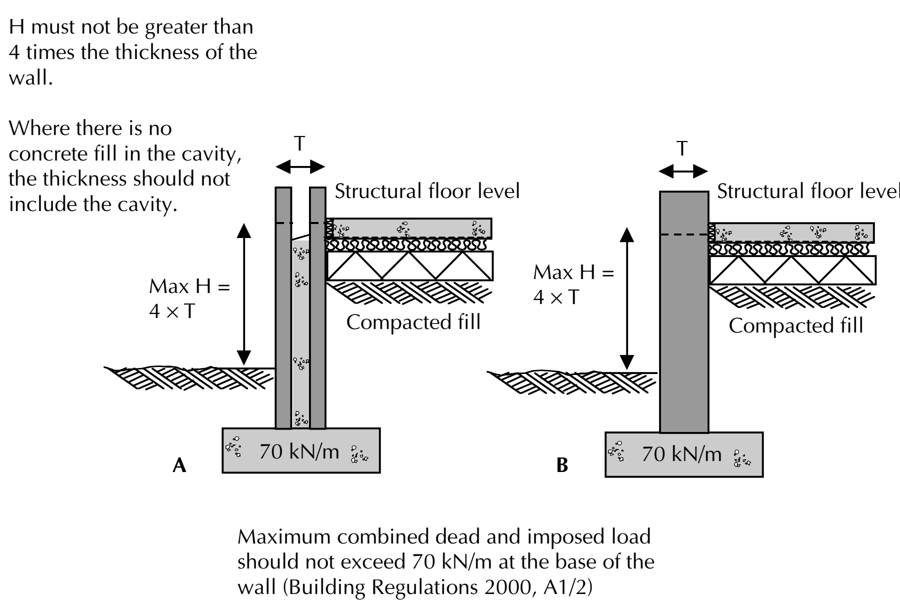


Figure 3.27 Depth of internal hardcore fill and external wall thickness.

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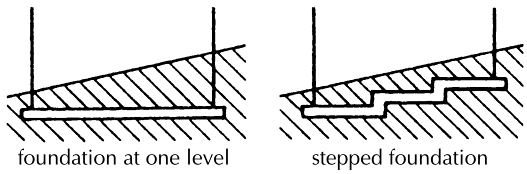


Figure 3.28 Foundation on sloping site.

so that each step is no higher than the thickness of the concrete foundation and the foundation at the higher level overlaps the lower foundation by at least 300 mm.

The loadbearing walls are raised and the foundation trenches around the walls backfilled with selected soil from the excavation. The concrete oversite and solid ground floor may be cast on granular fill no more than 600 mm deep or cast or placed as a suspended reinforced concrete slab. The drains shown at the back of the trench fill are laid to collect and drain water to the sides of the building.

Alternative approaches

With a growing number of alternative approaches to construction inspired by more sustainable architecture and also advances in prefabrication, some alternative approaches to traditional concrete foundations are being used.

Framed building resting on gabions is one such approach, see Figure 3.30. The idea here is that when the building has exceeded its life the structure and the foundation can be easily recovered, recycled and re-used with little loss of resources. Placing the gabions on the ground, rather than in the ground, can also help to reduce the health and safety risks associated with excavating

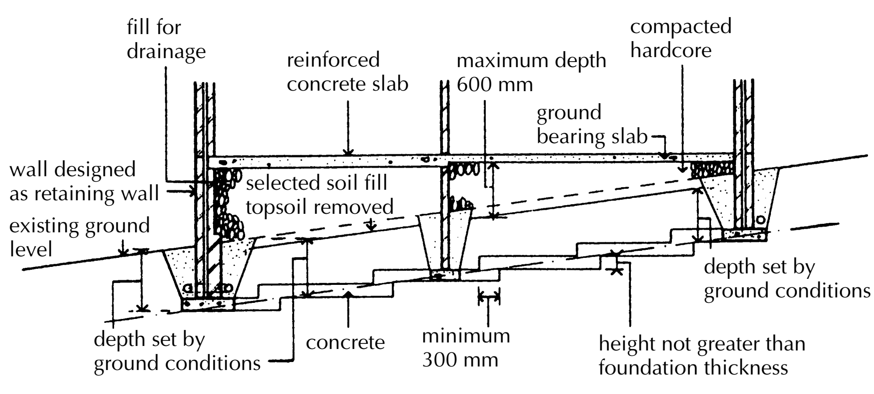


Figure 3.29 Stepped foundation.

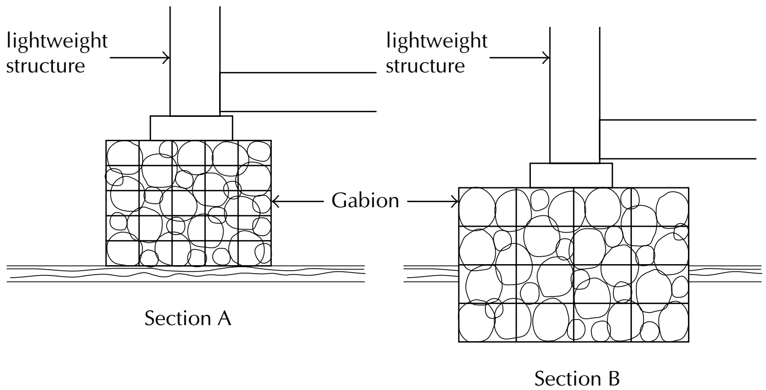


Figure 3.30 Gabion foundation, resting on (A) or in (B) the ground. Gabions can be made locally with recycled stone/materials.

foundations. Uses of such technology tend to be limited to small, often temporary, buildings. Structural calculations will be required to demonstrate compliance with the Building Regulations.

3.5 Site preparation and drainage

Turf and vegetable topsoil should be removed from the ground to be covered by a building, to a depth sufficient to prevent later growth. Tree and bush roots, which might encourage later growth and any pockets of soft compressible material, which might affect the stability of the building, should also be removed. The reasons for removing this vegetable soil are to prevent plants, shrubs or trees from attempting to grow; this would exert pressure on the concrete and crack it. Also once covered over, the vegetation contained in the soil will decay causing voids to form below the concrete. The depth of vegetable topsoil varies and on some sites it may be necessary to remove 300 mm or more vegetable topsoil.

Contaminants

In Approved Document C is a list of contaminants in, or on, ground to be covered by a building, that may be a danger to health or safety. Building sites that may contain contaminants can be identified from planning records or local knowledge of previous uses. Sites that are likely to contain contaminants include:

- Asbestos works
- Chemical or gas works
- Coal carbonisation plants and ancillary byproducts

- Industries making or using wood preservatives
- Landfill sites
- Waste disposals sites
- Metal works
- Munitions factories
- Nuclear installations
- Oil stores
- Paper printing works
- Railway land
- Scrap yards
- Sewage works
- Tanneries

Approved Document C also recommends action necessary if any contaminants are discovered, as described in Table 3.3.

Table 3.3 Possible signs of contaminants and actions.

Signs of possible contaminants	Possible contaminant	Relevant action
No sign of vegetation, or poor or unnatural growth	Metals Metal compounds	None
No sign of vegetation, or poor or unnatural growth	Organic compounds Gases	Removal
Surface colour and contour or materials may be unusual indicating waste	Metals Metal compounds	None
	Oily and tarry wastes	Removal, filling or sealing
	Asbestos (loose)	Filling or sealing
	Other mineral fibres	None
	Organic compounds including phenols	Removal or filling
	Combustible material including coal and coke dust	Removal or filling
	Refuse and waste	Total removal or seek specialist advice
Fumes and odours may indicate organic chemicals at very low concentrations	Flammable explosive and asphyxiating gases including methane and carbon dioxide	Removal
	Corrosive liquids	Removal, filling or sealing
	Faecal animal and vegetable matter (biologically active)	Removal or filling
Drums and containers (whether full or empty)	Various	Removal with all contaminated ground

Adapted from Approved Document C2, Table 2.

Site drainage

Surface water (stormwater) is the term used for rainwater and melted snow that falls on the surface of the ground, including open ground such as fields, paved areas and roofs. Rainwater that falls on paved areas and roofs generally drains to surface water (stormwater) drains and then to soakaways or mains drainage. Paved areas are usually laid to falls to channels and gullies that drain to surface water drains. Rainwater falling on natural open ground will in part lie on the surface of impermeable soils, evaporate to air, run off to streams and rivers and soak into permeable soils as ground water.

Ground water is that water held in soils at and below the water table (which is the depth at which there is free water below the surface). The level of the water table will vary seasonally, being closest to the surface during rainy seasons and deeper during dry seasons when most evaporation to air occurs.

In Approved Document C there is a requirement for 'adequate subsoil drainage', to avoid passage of ground moisture to the inside of a building or to avoid damage to the fabric of the building. Subsoil drainage is also required where the water table can rise to within 0.25 m of the lowest floor, where the water table is high in dry weather and where the site of the building is surrounded by higher ground.

Subsoil drains

Subsoil drains are used to improve the run off of surface water and the drainage of ground water to maintain the water table at some depth below the surface to:

- Improve the stability of the ground
- Avoid surface flooding
- Alleviate or avoid dampness in basements
- Reduce humidity in the immediate vicinity of buildings

Subsoil drains are either open jointed or jointed, porous or perforated pipes of clayware, concrete, pitch fibre or plastic. The pipes are laid in trenches to follow the fall of the ground, generally with branch drains discharging to a ditch, stream or drain. On impervious subsoils, such as clay, it may be necessary to form a system of drains to improve the run off of surface water and drain subsoil to prevent flooding. Some of the drain systems used are natural, herring bone, grid, fan and moat or cut-off.

Natural system

This system, which is commonly used for field drains, uses the natural contours of the ground to improve run off of surface ground water to spine drains in natural valleys that fall towards ditches or streams. The drains are laid in irregular patterns to follow the natural contours as illustrated in Figure 3.31A.

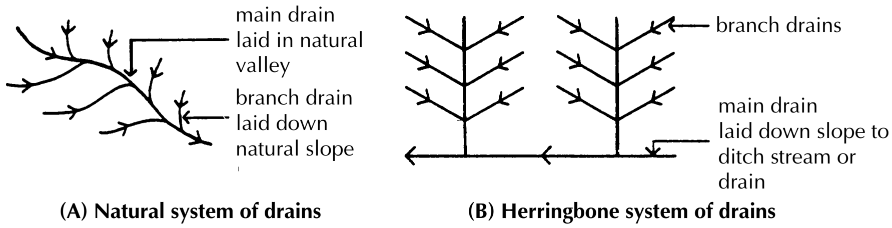


Figure 3.31 (A) Natural system. (B) Herring bone system.

Herring bone system

In this system, illustrated in Figure 3.31B, fairly regular runs of drains connect to spine drains that connect to a ditch or main drain. This system is suited to shallow, mainly one way slopes that fall naturally towards a ditch or main drain and can be laid to a reasonably regular pattern to provide a broad area of drainage.

Grid system

This is an alternative to the herring bone system for draining one way slopes where branch drains are fed by short branches that fall towards a ditch or main drain, as illustrated in Figure 3.32A. This system may be preferred to the herringbone system, where the run off is moderate, because there are fewer drain connections that may become blocked.

Fan system

A fan shaped layout of short branches, illustrated in Figure 3.32B, drains to spine drains that fan towards a soakaway, ditch or drain on narrow sites. A similar system is also used to drain the partially purified outflow from a septic tank to an area of subsoil where further purification will be effected.

On sloping building sites on impervious soil where an existing system of land drains is already laid and where a new system is laid to prevent flooding a moat or cut off system is used around the new building to isolate it from general land drains, as illustrated in Figure 3.33.

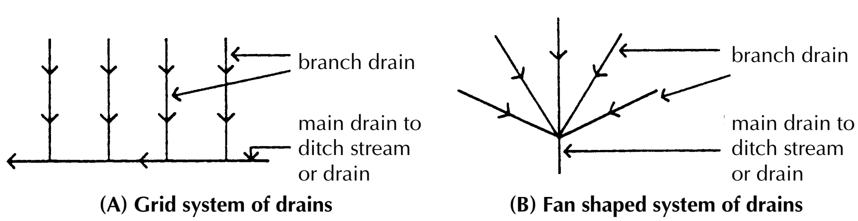


Figure 3.32 (A) Grid system. (B) Fan system.

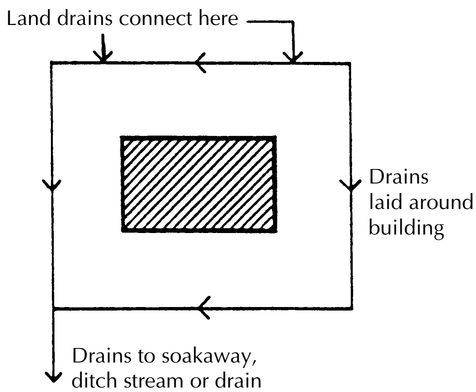


Figure 3.33 Moat or cut off system.

The moat or cut off system of drains is laid some distance from and around the new building to drain the ground between it and the new building and to carry water from the diverted land drains down the slope of the site. The moat drains should be clear of paved areas around the house.

Laying drains

Ground water (land) drains are laid in trenches at depths of 0.6 and 0.9 m in heavy soils and 0.9 to 1.2 m in light soils. The nominal bore of the pipes is usually 75 and 100 mm for main drains and 65 or 75 mm for branches. The drain pipes are laid in the bed of the trench and surrounded with coarse gravel (without any fine gravel). A filtering material (traditionally this was inverted turf or straw) is then placed on top of the gravel; this allows the water to percolate through to the drain without allowing fine material to pass through and block up the surrounding gravel. Excavated material is backfilled into the drain trench up to the natural ground level. The drain trench bottom may be

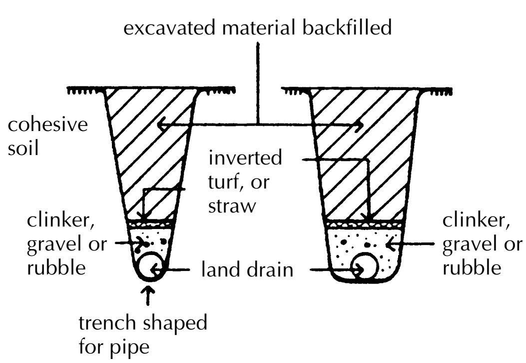


Figure 3.34 Land drains.

shaped to take and contain the pipe or finished with a flat bed as illustrated in Figure 3.34, depending on the nature of the subsoil and convenience in using a shaping tool.

Where drains are laid to collect mainly surface water the trenches are filled with clinker, gravel or broken rubble to drain water either to a drain or without a drain as illustrated in Figure 3.35 in the form known as a French drain. Whichever is used will depend on the anticipated volume of water and the economy of dispensing with drainpipes.

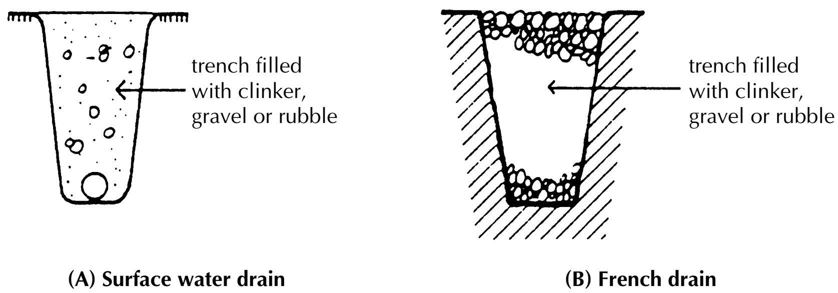


Figure 3.35 **(A) Surface water drain. (B) French drain.**

Support for foundation trenches

The trenches to be dug for the foundations of walls may be excavated by hand for single small buildings but where, for example, several houses are being built at the same time it is often economical to use mechanical trench diggers. If the trenches are of any significant depth it may be necessary to fix temporary timber supports to stop the sides of the trench from falling in. The nature of the soil being excavated mainly determines the depth of trench for which timber supports to the sides should be used. Working in trenches is dangerous and all health and safety guidance must be complied with in terms of providing adequate support for trenches and hence safe working conditions.

Soft granular soils readily crumble and the sides of trenches in such soil may have to be supported for the full depth of the trench. The sides of trenches in clay soil do not usually require support until a depth of approximately 1.5 m, particularly in dry weather. In wet weather, if the bottom of the trench in clay soil gets filled with water, the water may wash out the clay from the sides at the bottom of the trench and the whole of the sides above may collapse.

The purpose of temporary timbering supports to trenches is to uphold the sides of the excavation as necessary to avoid collapse of the sides, which may endanger the lives of those working in the trench, and to avoid the wasteful labour of constantly clearing falling earth from the trench bottoms.

The material most used for temporary support for the sides of excavations for strip foundations is rough sawn timber. The timbers used are square section

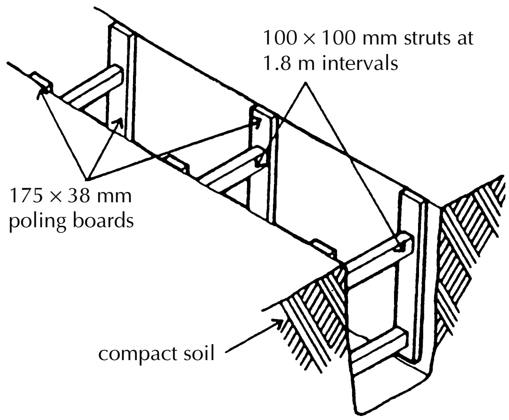


Figure 3.36 Struts and poling boards.

struts, across the width of the trench, supporting open poling boards, close poling boards and walings or poling boards and sheeting.

Whichever system of timbering is used there should be as few struts, that is horizontal members, fixed across the width of the trench as possible as these obstruct ease of working in the trench. Struts should be cut to fit tightly between poling or waling boards and secured in position so that they are not easily knocked out of place. For excavations more than 1.5 m deep in compact clay soils it is generally sufficient to use a comparatively open timbering system as the sides of clay will not readily fall in unless very wet or supporting heavy nearby loads. A system of struts between poling boards spaced at about 1.8 m intervals as illustrated in Figure 3.36 will usually suffice.

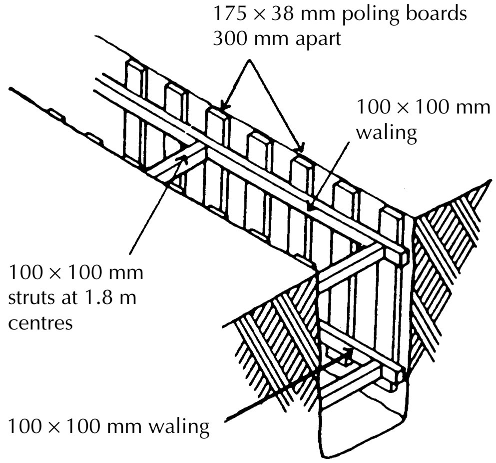


Figure 3.37 Struts, waling and poling boards.

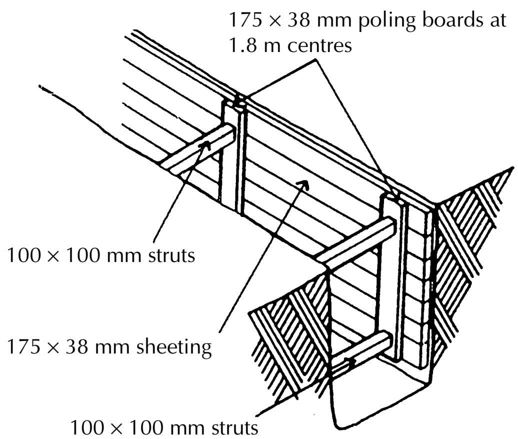
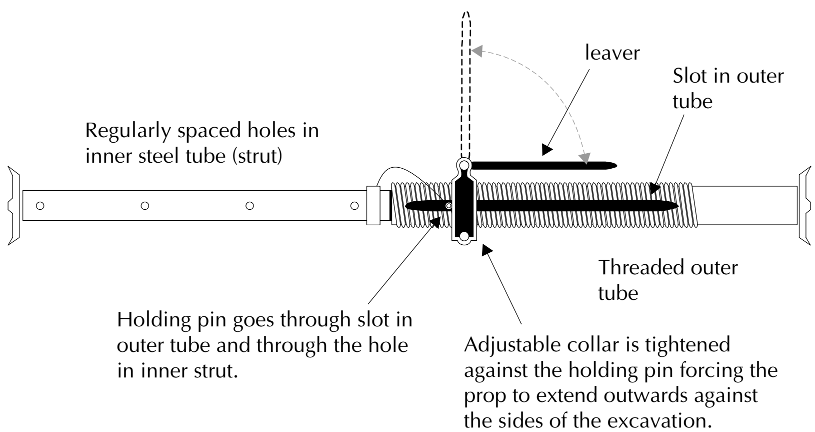


Figure 3.38 Struts, poling boards and sheeting.

Where the soil is soft, such as soft clay or sand, it will be necessary to use more closely spaced poling boards to prevent the sides of the trench between the struts from falling in. To support the poling boards horizontal walings are strutted across the trench, as illustrated in Figure 3.37.



Standard sizes of strut available	
Extension in metres	
Closed	**Open**
0.495	0.737
0.705	1.137
1.029	1.740

Figure 3.39 Adjustable steel strut.

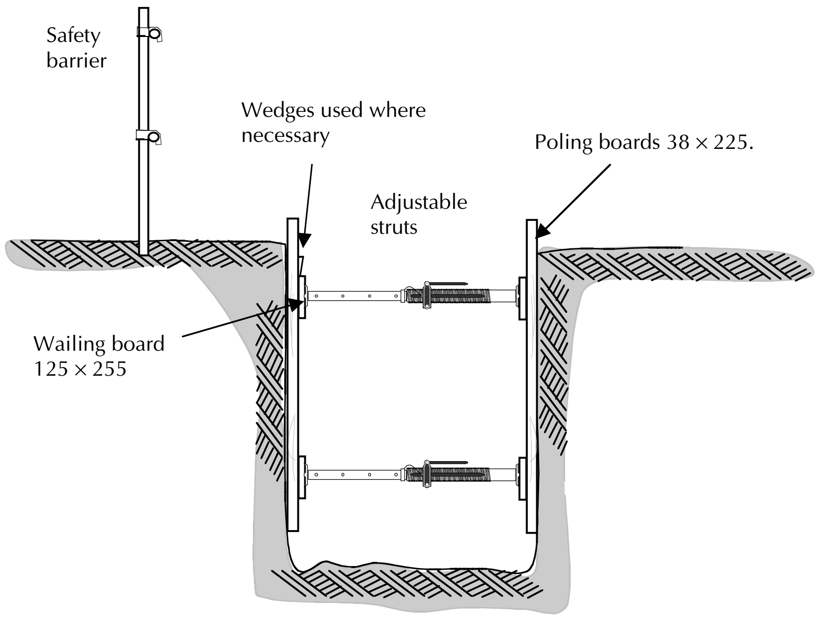


Figure 3.40 Open or closed timbering using adjustable steel strut.

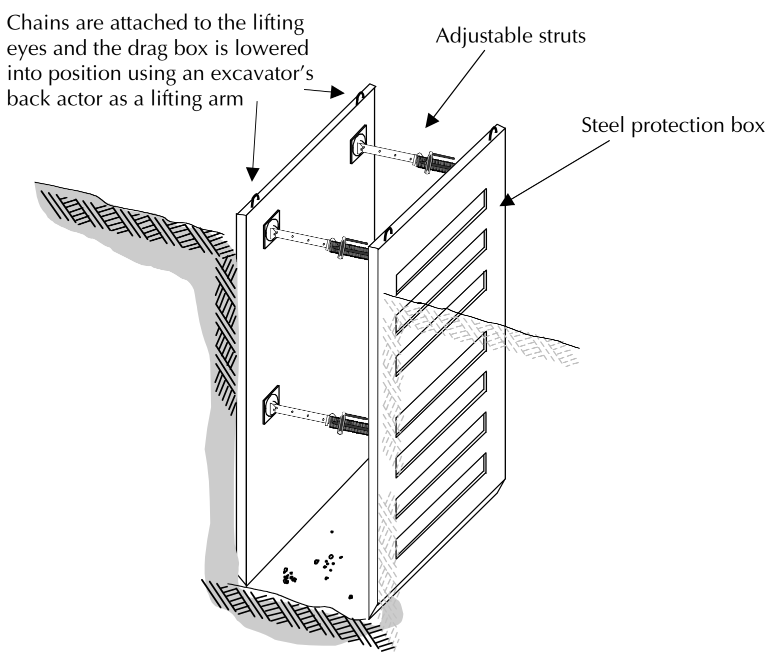


Figure 3.41 Trench box.

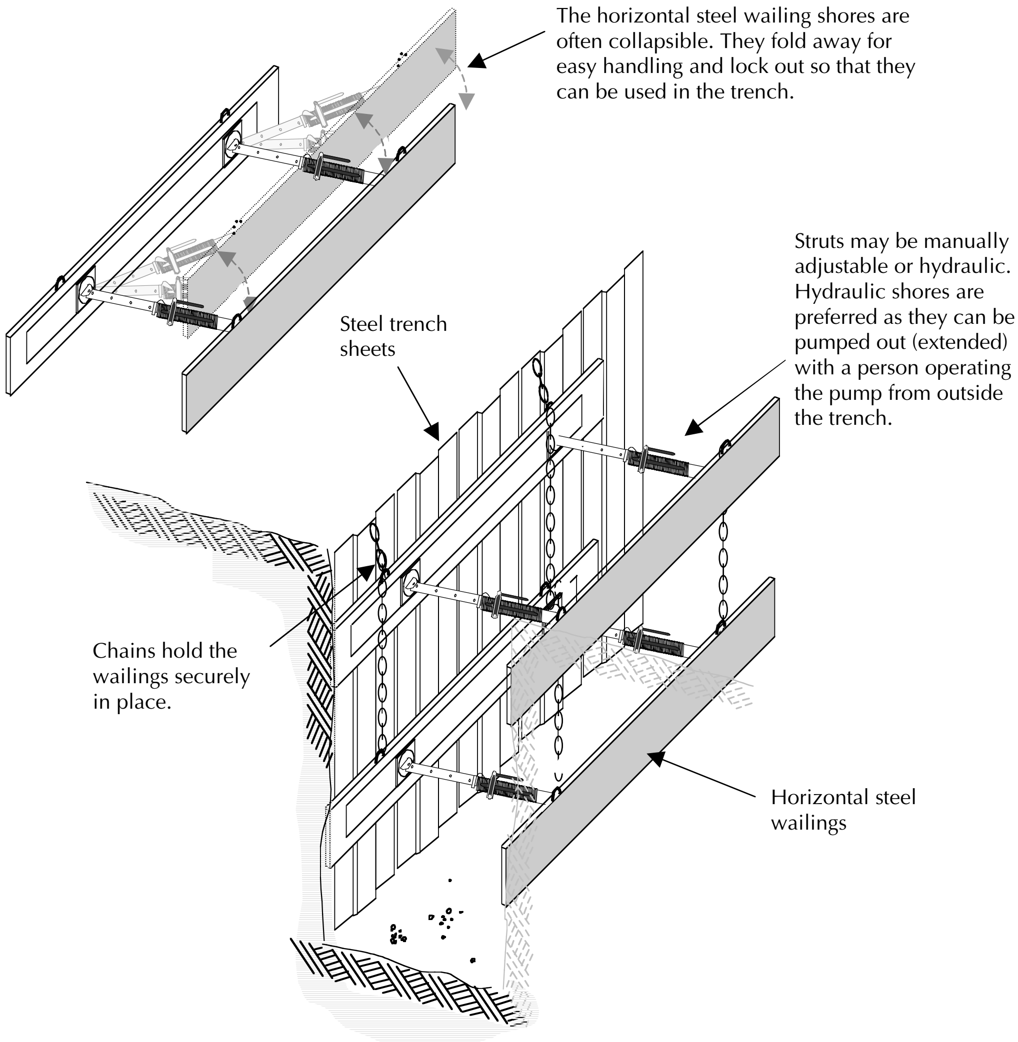


Figure 3.42 Shoring: horizontal steel wailing.

For trenches in dry granular soil it may be necessary to use sheeting to the whole of the sides of trenches. Rough timber sheeting boards are fixed along the length and up the sides of the trench to which poling boards are strutted, as illustrated in Figure 3.38. The three basic arrangements of timber supports for trenches are indicative of some common systems used and the sizes given are those that might be used.

Although the traditional method of timbering is still used to provide temporary trench support it is more common to use steel shoring systems such as steel walers, adjustable vertical shores, adjustable props, trench sheets and trench boxes as illustrated in Figures 3.39–3.43.

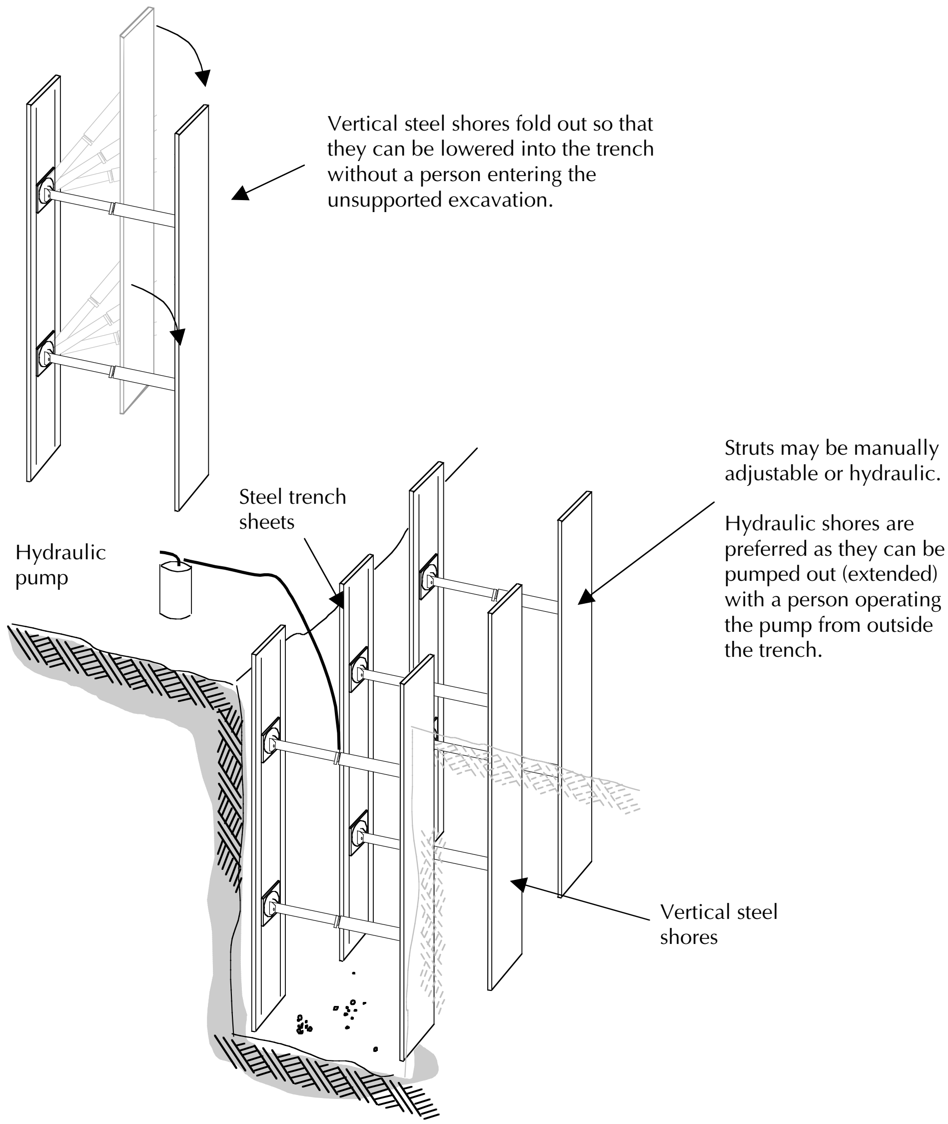


Figure 3.43 Shoring: vertical steel wailing.

If timbering is used for temporary support it is used with adjustable steel struts instead of timber struts. Trench boxes are often used because they provide a safe area in which to work. However, trench boxes cannot be used where services cross the excavation. Because trench support has to be chosen to suit particular site conditions it is common to find a combination of systems in more complex situations.