5 Foundation Failures

5.1 Introduction

Architects, surveyors and structural engineers are all called upon at some time to examine defective foundations and submit reports with recommendations for remedial action. Whilst we can all learn the technicalities that form the basic knowledge of the various building professions, there is always one element where the professional has to rely on skill to diagnose the significance of any symptoms: that is 'experience'. This applies especially to the analysis of foundation problems and their cause.

5.2 Causes of failure

Foundations can move as a result of loads applied causing a downward movement known as settlement. Settlement can be tolerated by the structure provided the loads do not exceed the 'allowable bearing pressures' stated in BS 8004. Other possible causes of foundation movement known as subsidence, brought about by activity in the ground, are:

- Soil erosion caused by flowing water.
- Changes in ground water level.
- Buildings on made up ground.
- Movement associated with mining activities or 'swallow holes' found in chalk.
- Movement due to shrinkage or swelling of clay soils. This is the most common cause of foundation movement.
- Uneven bearing capacities of differing subsoils.

Heave is the upward movement of the ground. It is the result of an increase in moisture content in excess of that which existed when the building was erected. It can occur when trees are removed, but it can be caused by the interruption of a natural water course through climate change. Heave is also caused by the removal of loads on the foundation. A rather uncommon form of heave is when the ground

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expands when frozen. The problem is usually confined to soils consisting of fine sand and chalk. Where the water table is high and there are prolonged periods of freezing, ice layers can cause the foundations to lift, but this only occurs during very severe winter conditions.

Although other possible causes of damage must be considered during the investigation, settlement, subsidence and heave account for damage to most structural elements including floors in low-rise buildings (Dickinson & Thornton, 2004). Typical symptoms are:

- Cracks in external or internal walls. The cracks may be hairline or much wider.
- Walls bulging or leaning out of vertical.
- Floors slanting out of level.
- Drains or service pipes blocked or malfunctioning.
- Pavings or drives cracking.

When foundation defects are to be investigated a thorough examination is imperative. The primary object of this type of examination is to obtain an accurate diagnosis as a basis for a report. It is therefore extremely important that all available evidence is collected together and carefully examined before decisions are reached as to the method of repair to be adopted. This inspection may take some considerable time, but it is essential that extensive defects are properly investigated. It is always advisable to bear in mind when making a diagnosis that more than one cause may be responsible for a defect, although it is necessary to investigate the primary cause. For example, foundation movements may have been responsible for a fractured external wall, but rainwater could penetrate the fracture causing dampness on the internal face of the wall. Although the two defects will have to be remedied it does not necessarily mean that the crack has caused rainwater to penetrate the wall. The wall may have been damp before the movement took place perhaps due to faulty construction or porous brickwork.

Foundation repairs to existing buildings are generally the most difficult and costly to effect, which is still a good reason why a thorough investigation should be carried out. The object of the investigation will be to determine the nature and strength of the subsoil under load. A visual observation below ground can only be carried out by digging trial holes at intervals along the length of the wall adjacent to the suspected position of the foundation failure. The holes should be of a size to accommodate an adult.

When the underside of the foundation is exposed, the details of the subsoil, together with the condition of the foundation and base of the wall should be recorded. Tests can be carried out by driving an iron bar into the subsoil. A more detailed test for moisture and bearing capacity can be carried out by removing samples of soil with a spade and submitting them to a laboratory for examination.

The surveyor should always bear in mind that the initial examination will only reveal conditions as they are, and they will need to be studied over a period of time before a decision can be made. Prior to carrying out an inspection of the foundation defects it is advisable to have a precise knowledge of the soils present on site. Land used for building varies considerably from hard rock to loose sand. Between these extremes are soft rock, firm earth, firm clay, soft clay, gravel, sand and fill. Soils may be divided into two categories, non-cohesive and cohesive:

- Non-cohesive soils are the gravels and sands which tend to lack cohesion and have no plasticity.
- Cohesive soils are the various types of clay and silt and possess cohesion and plasticity.

Below are the principal causes of foundation failures that are considered to be most common in the UK.

5.3 Differential movement

Excavating the ground and placing substantial loads on it is sufficient to cause a slight movement as the ground below is compressed to resist the load. Provided the settlement is uniform over the building area the movement does little damage. Alternatively, there may be differential movement where part of the foundation remains stable while the remainder moves (Richardson, 2000). A typical example of differential movement is shown in Figure 5.1 where settlement occurred in the end walls with the centre portion stable. The cracks are usually vertical or diagonal and are often interrupted by window or door openings. In such cases a gap is formed between the frame and brickwork.

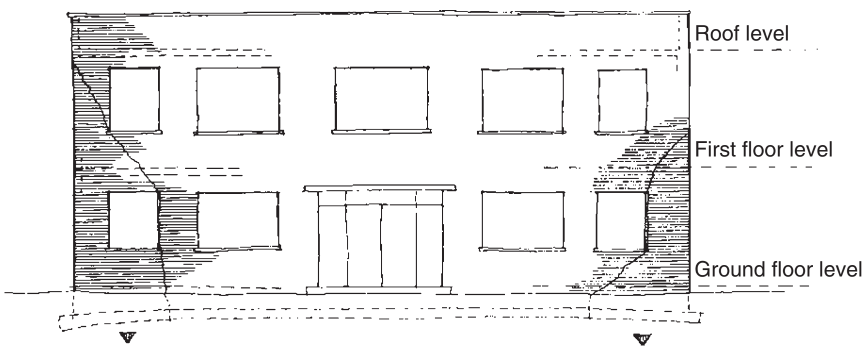

Figure 5.1 Example of differential settlement. Settlement in end walls with centre portion stable. Cracks increase in width with height, and appear to be interrupted by the windows, but in fact extend round the openings forming a gap between window frame and brickwork. The movement is at its maximum at roof level and could cause loss of bearing in the roof slab

5.4 Inadequate foundations

This can be due to the fact that the width of the foundation concrete is not enough to support the building load. In such cases it may be necessary to consider increasing the depth of the foundations by underpinning to a point where the safe bearing capacity of the ground is adequate (IstructE, 2000). On the other hand it is not surprising to find that most buildings erected before the nineteenth century have no foundations and the brick or stone walls were laid directly on the earth or on a bed of consolidated rubble. Occasionally, two or three courses of brick footings were laid on the bed of the excavation to spread the load in lieu of a concrete base.

5.5 Overloading

Every building has its own pattern of loading. Where internal alterations have taken place in the original building or additional loads have been applied due to a change of use, then the loads placed on the subsoils are greater than was originally allowed for. Overloading can also occur where door or window openings have been enlarged which may result in a heavier load being transferred to an adjacent section of brickwork consisting of a narrow pier. Again, the load imposed upon the subsoil is greater than originally allowed for, causing the pier to settle (see Figure 5.2).

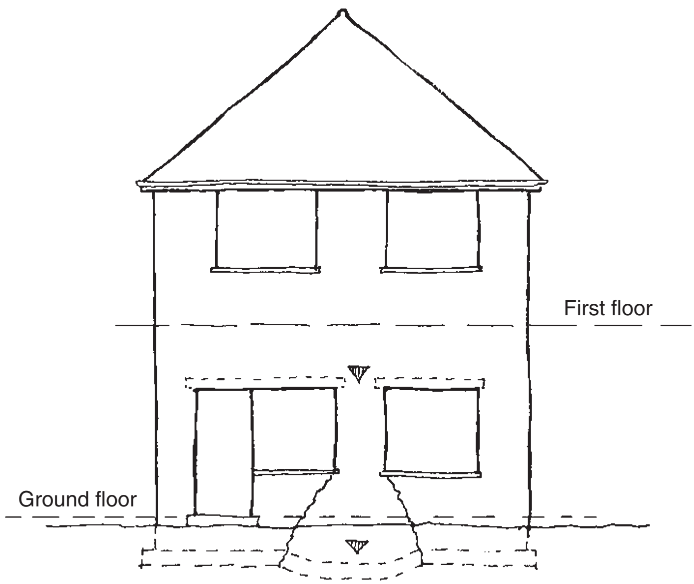

Figure 5.2 Example of overloading. Settlement in the centre of a wall with ends stable. Heavy loads from first floor, roofs and walls above are transferred to a narrow pier of brickwork causing cracks in the wall and foundation settlement. With this type of settlement cracks decrease in width with height

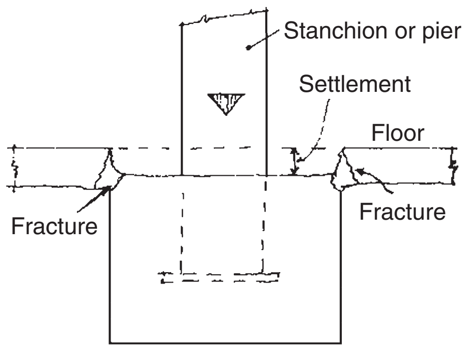

Figure 5.3 Differential settlement under the point load of a stanchion

Under concentrated loads such an overloaded pier or stanchion on shallow foundations will often show movement cracks between floor and foundation where the foundation has been 'punched' downwards sometimes several centimetres (see Figure 5.3).

The average domestic building, however, is unlikely to weigh more than 45 kg per metre length of wall with a nominal concrete base width of, say, 680 mm. The naturally occurring subsoils found in the UK are usually able to sustain this type of loading, provided the foundation is deep enough not to be disturbed by the effects of atmospheric action.

5.6 Unequal settlement

Shallow foundations on clay present bearing capacity problems and shrink and expand due to seasonal changes, the effect being felt to a depth of 1.4 m. The bulk of these clays are situated in the southeast of England which has the lowest rainfall (Driscoll & Crilly, 2000).

The clay soil immediately surrounding a building will shrink and crack during hot weather, but underneath the building the subsoil will be protected from the winter rains and also from the hot sun; thus it will expand and contract much less. Therefore, a differential settlement is set up causing the foundations to the external walls to settle downwards and the walls to lean outward during the hot summer months when the subsoil is dry, and a tendency to lean inwards in the winter months when the exterior wet clay has expanded and the interior has remained stable. During the wet seasons when the clay expands the cracks tend to recover. This movement can also cause diagonal fractures around window and door frames and a drop in the horizontal joints of a string course or bed joints in brickwork. The appearance of cracks in the outer walls can be disturbing, so that this seasonal movement can often cause considerable concern out of all proportion to its actual importance (Richardson, 1996, 2000).

5.7 Effect of tree roots

Fast growing trees close to buildings can cause unequal settlement when active tree roots dry out the soil causing differential soil shrinkage (BRE Digest 298, 1999). Shrinking clays affect the bearing capacity and lead to movement in the building, especially in shallow foundations. Tree roots can extend over a considerable distance and can extract moisture from as deep as 6 m below the surface. It is, therefore, necessary to make an accurate survey of their position and obtain details of the type of tree, and at the same time establish that the tree is the cause of the damage (see Figure 5.4). Poplars and elms with fast growing root systems can be expected to cause serious seasonal movements.

One way to avoid root problems with tall trees is to maintain a 'safe distance' between the tree and the building. Some species of trees are likely to cause more problems than others. Table 5.1 shows the different types of trees known to have caused damage, ranking in descending order of threat. It also shows their expected maximum height on clay soils. Planting a tree close to a new or existing building will usually entail some risk of damage. It is, therefore, suggested that the recommendations described in Table 5.1 are followed.

Buildings can also be damaged when well established trees are removed (Bonshor & Bonshor, 1996). The resultant pressures due to the removal of trees and bushes act both vertically and horizontally. In the majority of cases it is the horizontal movement that produces the greatest damage, particularly in the upper layer of clay. In such cases there is a danger of the clay expanding over a period of years as it reabsorbs moisture causing the foundation to 'heave' as described in Section 5.2 above. Where window sills crack and rise in the middle this is an indication of soil

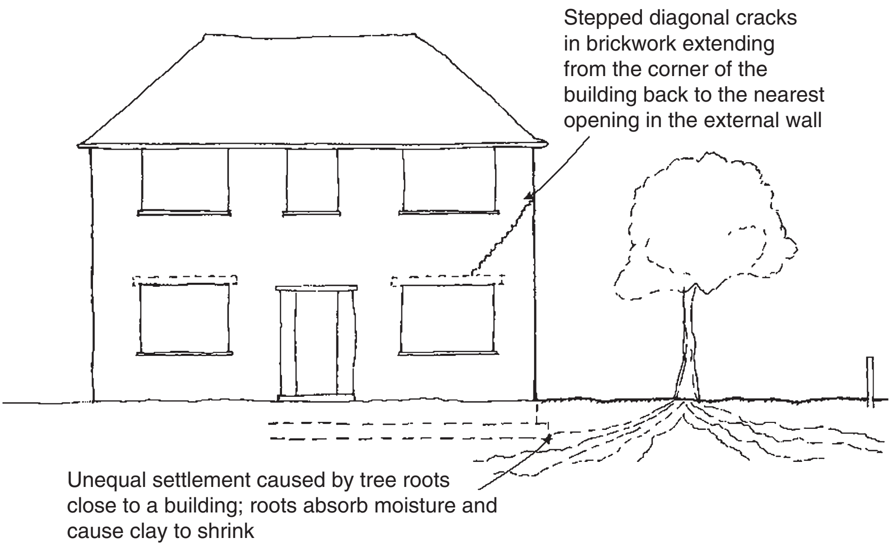

Figure 5.4 Unequal settlement caused by tree roots

Table 5.1 Risk of damage by different tree species: the table shows for each tree species the distance between tree and building within which 75% of the cases of damage occurred. Reproduced from the Building Research Establishment Digest 298 by permission of the Controller HMSO: Crown copyright

Ranking	Species	Max tree height – H (m)	Max distance for 75% of cases (m)	Min recommended separation in very highly and highly shrinkable clays
1	Oak	16–23	13	1H
2	Poplar	24	15	1H
3	Lime	16–24	8	0.5H
4	Common ash	23	10	0.5H
5	Plane	25–30	7.5	0.5H
6	Willow	15	11	1H
7	Elm	20–25	12	0.5H
8	Hawthorn	10	7	0.5H
9	Maple/ sycamore	17–24	9	0.5H
10	Cherry/plum	8	6	1H
11	Beech	20	9	0.5H
12	Birch	12–14	7	0.5H
13	White beam/ rowan	8–12	7	1H
14	Cypress	18–25	3.5	0.5H

heave. Differential movements will take place resulting in cracks in walls and partitions. In such cases the removal of a tree may do more harm than good.

5.8 Shallow foundations

The surveyor will often find that foundation movement in older domestic properties can be caused by light strip foundations attached to the main building supporting porches, bay windows and garages. There is a common misconception that these lightweight structures do not need deep foundations as does the main building. If this type of foundation is not carried down sufficiently deep to avoid movement by atmospheric action, the junction between the light and heavy parts of the structure will often show a diagonal crack running down from the lower corner of the rear window as shown in Figure 5.5.

Another common example is when part of a building has a basement with foundations set in deep geological beds. Seasonal movement will often take place in the foundations close to the surface causing a vertical fracture at the junction between the walls built off the basement wall and the ground floor. The heavier walls to the basement area will settle relatively more causing movement cracks between the light and heavily loaded walls as shown in Figure 5.6. This is more noticeable when the ground floor structure is built on shallow foundations in a clay subsoil.

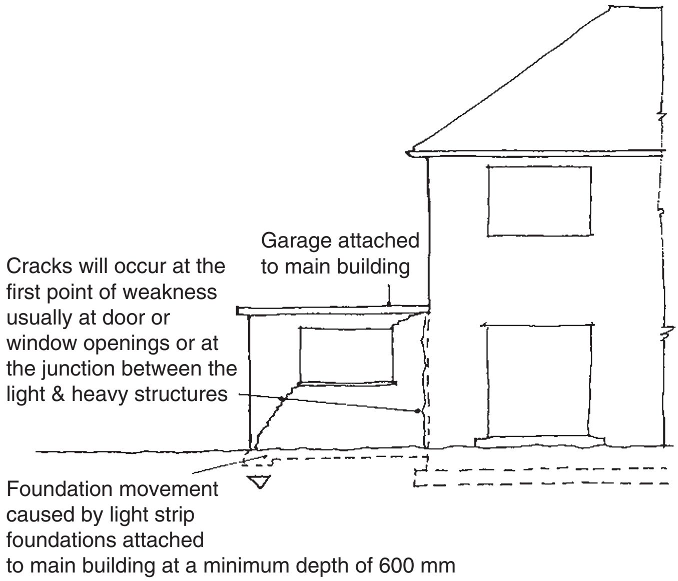

Figure 5.5 Diagonal fracture between light and heavy structure

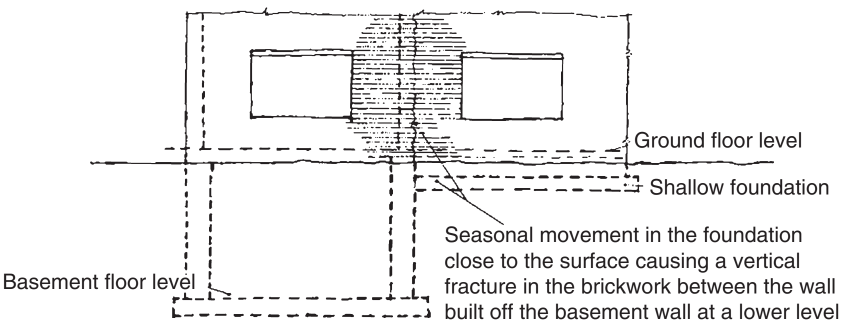

Figure 5.6 Unequal settlement between basement and ground floor walls

5.9 Building on sloping sites

Buildings on sloping clay sites can often present difficulties (IstructE, 2000). The water table on sloping sites tends to follow the topography of the surface and if the natural contours of the site change it does not necessarily alter this line. Where the foundations have been set at a constant depth from the stepped level surface the concentrations of water may affect the foundations at the lowest point causing differential settlement. Figure 5.7 shows such a case where the water table is above the foundation at the highest point and beneath a shallow foundation at the lowest

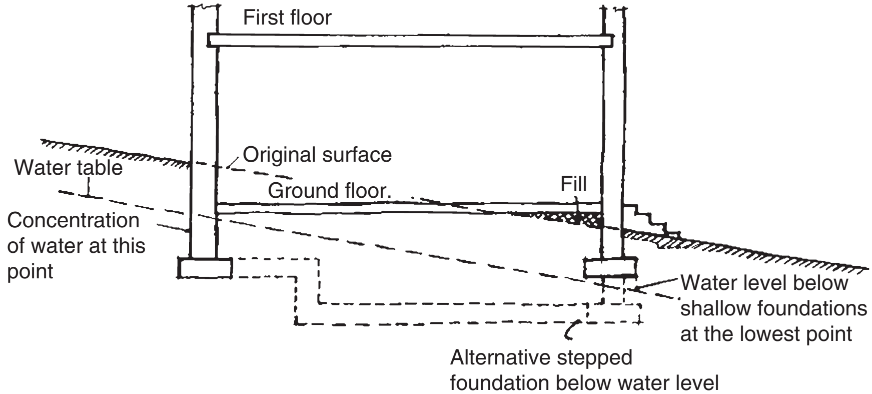

Figure 5.7 Building on sloping clay site

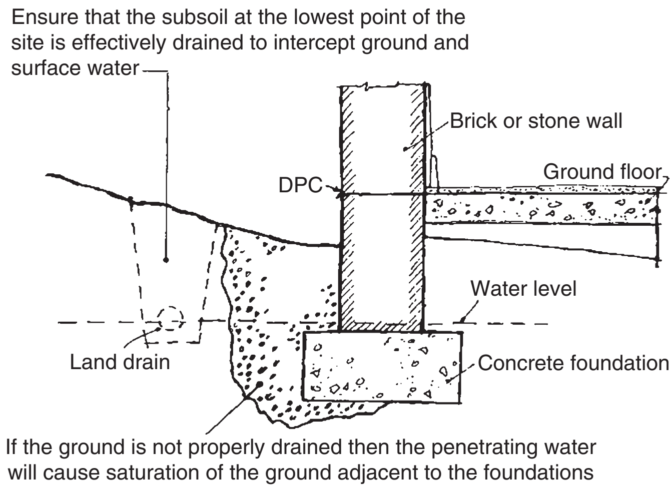

Figure 5.8 Building at the lowest point of a sloping site

point. In such cases it would have been advisable to form stepped foundations as shown in the sketch in order to be below the water level.

If a building is erected at the lowest point of a sloping site, natural drainage of the water to the lower points can cause saturation of the ground around the base of the wall and foundations thus lowering the bearing capacity (see Figure 5.8). In both the above cases it is advisable to check that the subsoil is effectively drained at the highest level in order to protect the building against damage by water penetration. The surveyor will often find that surface water drainage has been omitted especially in ancient buildings.

A similar case of water penetration often occurs around the base of the external walls of old buildings where the ground floor level is below the ground level. The

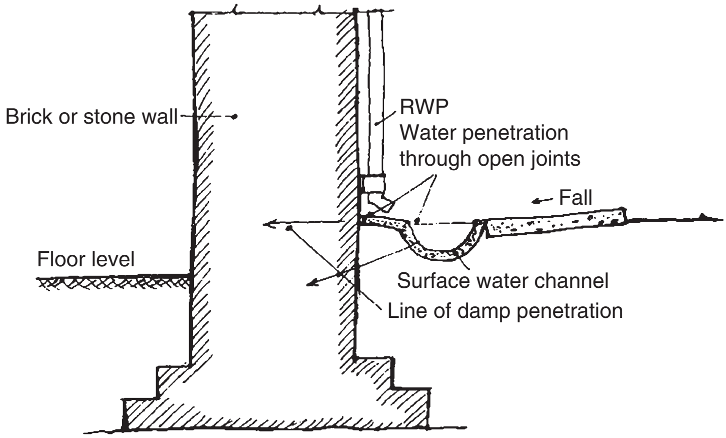

Figure 5.9 Water penetration around base of external walls where the ground floor level is below the ground level

surveyor will probably notice that clayware or concrete channels have been inserted around the base of the wall to collect rainwater from the roofs and a certain amount of surface water from paved areas around the building. The channels tend to move with the seasonal changes in the subsoil causing the joints to open, thus allowing water to percolate through to the subsoil and the base of the wall. In such cases there is a risk of uneven movement in the subsoil leading to settlement cracks (see Figure 5.9).

In chalk and limestone areas, cavities in the subsoil can be formed by underground streams or watercourses dissolving the rock. If the sandy overburden falls into the cavity the foundations will drop. These cavities are known as 'swallow holes'. In the three cases described above the foundations need protecting and the ground water must be directed away from the foundations by a system of ground or surface water drainage.

5.10 Building on made up ground

Filled or made up ground is extremely varied in form and should be treated as suspect. Experience has shown that the majority of foundation failures on filled ground have been due to the use of poor fill, and inadequate compaction. Unfortunately, during an inspection, detailed knowledge of the fill is usually lacking. All possible information concerning the site should be obtained by discussion with the local authority and by studying local maps of the area. Apart from digging trial holes the surveyor should observe signs of damage to any adjacent buildings. The trial holes should be deep enough to enable the surveyor to assess the nature of the fill, its depth, composition and degree of compaction. If any remedial work is contemplated, such as underpinning or piling, this could well involve the protection and support of the services to the building. A particular note of this matter should be made during the site examination.

5.11 Diagnosis

Crack monitoring may be necessary to see whether the problem is still active (Bonshor & Bonshor, 1996). This should be done by the application of 'tell-tales'. Tell-tales should be fixed internally and externally if found necessary. Although tell-tales are most important from the surveyor's point of view, it will sometimes be difficult to explain the size and direction of the crack to the client by way of notes and sketches. In this respect photographs will be most useful when attached to a report. However, the tell-tales will enable the surveyor to check whether or not the movements are progressive. Movements due to settlement of filled ground usually cause major cracking of external walls and partitions. Bulging can also occur in external walls. Concrete ground floors are also liable to lift and crack.

After all investigations have been completed the surveyor may consider obtaining the services of a specialist in this field to advise on any remedial work required.