3 INVESTIGATION AND TREATMENT OF MINE WORKINGS AND UNSTABLE GROUND

Chapter contents

continued...

3 INVESTIGATION AND TREATMENT OF MINE WORKINGS AND UNSTABLE GROUND

3.1 Introduction

Mining instability occurs as a result of collapse of the underground workings, or from the collapse of shafts or adits which lead to the workings. This gives rise to general or localised subsidence of the ground surface. The term subsidence is generally used to refer to vertical displacement, but a degree of horizontal movement may also accompany the downwards movement of the surface.

Apart from subsidence due to underground mining, subsidence may also occur for a variety of other reasons, such as: soil compaction, soil shrinkage, lowering of the water table, collapse of natural underground cavities, earthquakes or volcanic activity.

Most early workings for both coal and iron ore were carried out at surface outcrops. Underground mining from bell pits, drifts or adits did not generally take place until around the fourteenth century. The use of room and pillar methods (see Section 3.2.3) was not introduced until around the seventeenth century. Modern mining for coal and iron ore may involve opencast or underground mining techniques.

Modern opencast mining sites worked in accordance with good practice are reinstated in a controlled manner to an agreed programme of restoration. Nevertheless, subsidence of the backfilled material often continues for many years after restoration as a result of consolidation settlement.

Modern underground mining techniques for coal, and sometimes iron ore, generally involve total extraction by longwall methods. The resulting ground subsidence is usually predictable and rapid. However, extraction of coal from modern mines using room and pillar methods is still practised in some areas.

Mining subsidence can have a significant effect on buildings, infrastructure and utility services, and will therefore result in a safety hazard. Photographs 3.1 and 3.2 show examples of typical subsidence damage to buildings. Damage occurring as a result of subsidence varies depending on the method of mining, the degree of movement involved and whether any structural precautions were taken to counteract the effects of anticipated subsidence.

When planning a development on a site which may be affected by mine workings, investigations should be carried out to establish the nature and extent of any workings and what effect any future subsidence may have on the proposed development (see Section 3.4). The investigations should be designed and carried out so as to enable the design team to determine the treatment which may be necessary to stabilise shafts, adits or shallow workings, and any special precautions required in the design of foundations buildings and other structures.

3.2 Causes and effects of mining subsidence

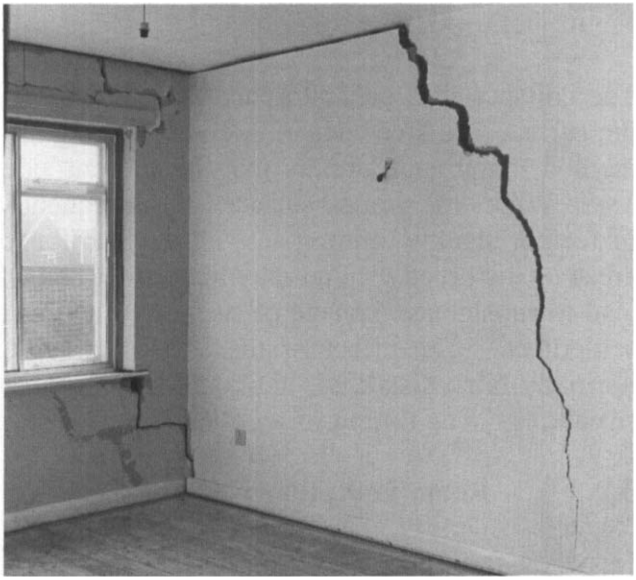
3.2.1 Factors affecting subsidence

The extraction of coal and other minerals by underground mining inevitably involves the risk of mining subsidence. Different mining methods and the type of subsidence which may be produced, and their effects on structures, have been well researched and are discussed in the following sections.[114, 126, 250, 251, 257]

The effect of mining subsidence varies considerably depending on factors such as:

- the type of mining carried out;
- the depths of the workings;
- the nature and condition of the overlying strata;
- the effects of changes in site conditions;
- the sensitivity of buildings, infrastructure and utility services to subsidence damage.

Photograph 3.1: Example of external structural damage caused by mining subsidence (source: British Coal)



Photograph 3.2: Example of internal structural damage caused by mining subsidence (source: British Coal)

3.2.2 Bell pits

Bell pits were used in early shallow workings for coal and iron ore. The technique involves sinking a shallow shaft of about 1m diameter down to the seam. Depths of bell pits varied depending on the extent of overburden and the thickness and quality of the seam, but rarely exceeded 12m. Mining proceeded radially from the base of the shaft until the area became too large to be naturally or artificially supported, or problems of ventilation and water ingress occurred. The pit was then abandoned and a new pit started nearby. Bell pit diameters of 8 to 20m have been recorded. In areas of intensive mining, shafts have been found as close together as 8 to 10m.

Surface evidence of the existence of bell pits can take the form of cones of mine waste around the top of the shaft, or numerous depressions along the outcrops of major seams. The pits were often partly backfilled or simply left to collapse after abandonment. Areas containing bell pits present a risk of continued mining subsidence due to the collapse of voids, or due to the poor bearing capacity of the disturbed ground (see Figure 3.1).

The collapse of a bell pit generally leads to the formation of a crater at the surface. In areas where intensive mining has been carried out by this method many such craters may be present side by side within a small area. Where the ground surface has subsequently been regraded the signs of former shallow mining activity may no longer be visible. However, areas of disturbed ground may be present below the surface which could lead to subsidence damage of surface structures as a result of differential settlement. The effect of the sudden collapse of a single bell pit is normally fairly localised, but could lead to subsidence damage of nearby structures. The timing of a collapse cannot be predicted.

3.2.3 Room and pillar workings

In water-free conditions or in situations where water could drain naturally, room and pillar methods were developed. These methods became more widespread with the introduction of steam pumps.

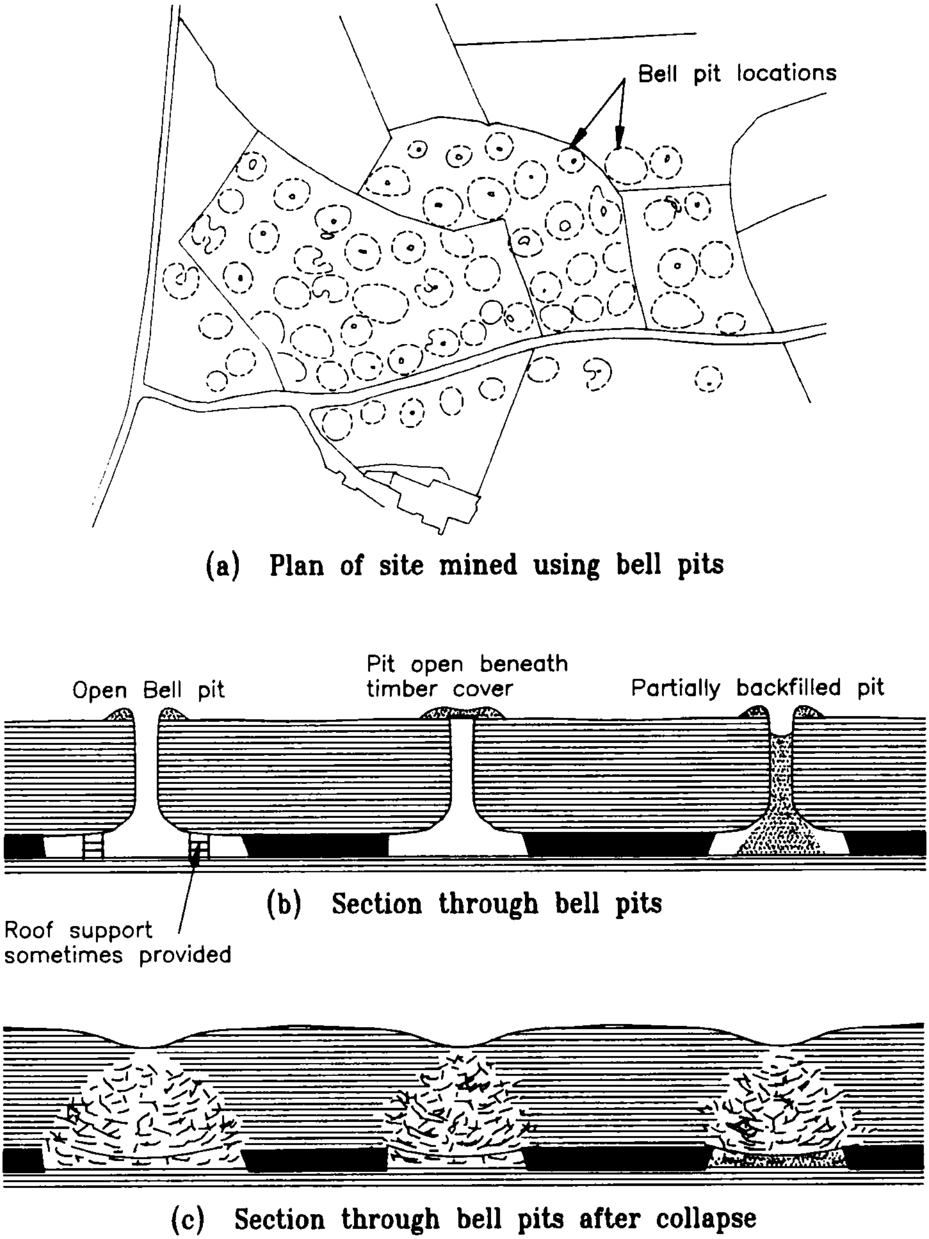


Figure 3.1: Bell pits

Unworked pillars of coal or iron ore were left in place to support the roof of the workings.

Regional variations occurred in the room and pillar layout. For early mines the room widths were usually determined on a trial basis. Room widths for later mines tend to vary between 2 and 5m, with pillars initially 10 to 12m square. After initial extraction pillars were often reduced in size or removed completely as the workings were abandoned. For deeper workings in the UK, pillar widths normally exceed 10% of the working depth to ensure pillar stability.

Areas of room and pillar workings present a risk of mining subsidence due to: roof failure, pillar failure, floor heave, or a combination of these effects (Figure 3.2). Voids resulting from a collapse may cause surface effects such as craters or 'crown holes' to appear. Sometimes the collapse of a group of pillars may occur, leading to localised subsidence.

Pillar collapse may occur naturally or may be triggered by external factors such as:

- surface loadings including those due to embankments, spoil heaps or building foundations;
- undermining by total or partial coal extraction;
- seismic shocks occurring either naturally or due to the collapse of longwall workings.

The condition of room and pillar workings is difficult to establish and the timing of any collapse cannot easily be predicted. Formation of a crown hole is likely to lead to differential settlement and subsidence damage of nearby structures. Areas of disturbed ground due to former collapses may also lead to reductions in allowable bearing pressures and possible subsidence damage.

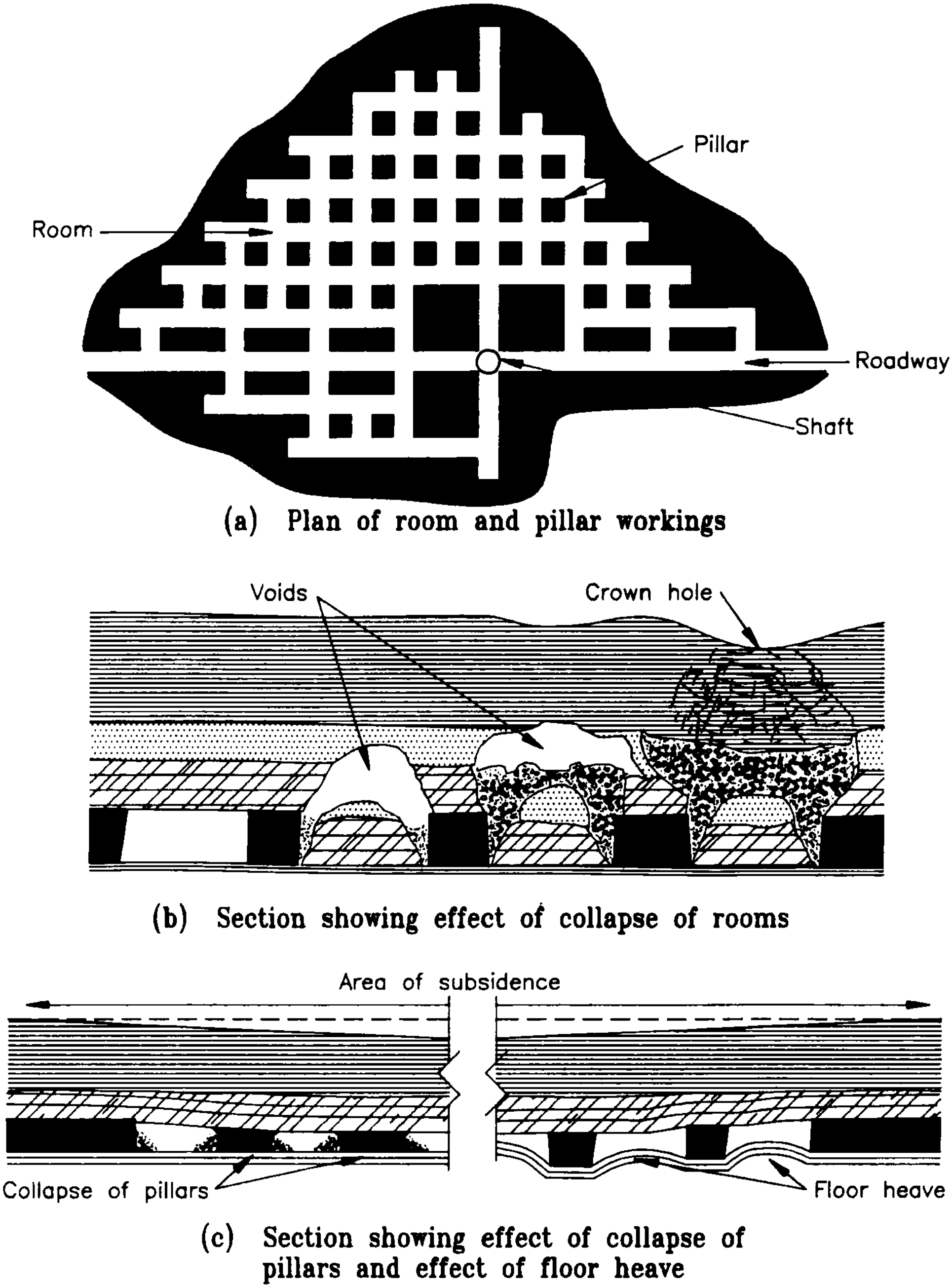


Figure 3.2: Room and pillar workings

3.2.4 Drift mining

Drift mining was carried out in situations where seams had a shallow dip, and the outcrop was either at the surface or beneath a shallow soil cover. Coal was originally obtained from the adit or 'drift', or from connectors between drifts. Such drifts were comparatively short in length.

Subsidence may occur due to the collapse of the drifts, or due to the poor bearing capacity of the disturbed or previously collapsed ground.

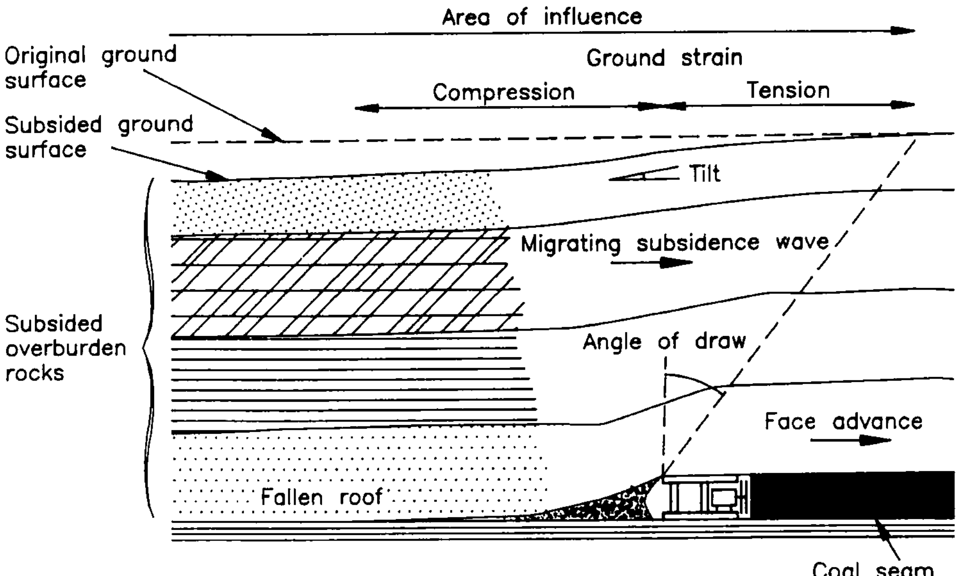
3.2.5 Longwall mining

Longwall mining involves the working of a single coal face with access from roadways at right angles to the face at each end of the seam. The working face is temporarily supported, the support being advanced as the face is worked, allowing the roof to collapse into the space behind the workings (Figure 3.3). Modern workings typically involve face lengths of up to 300m.

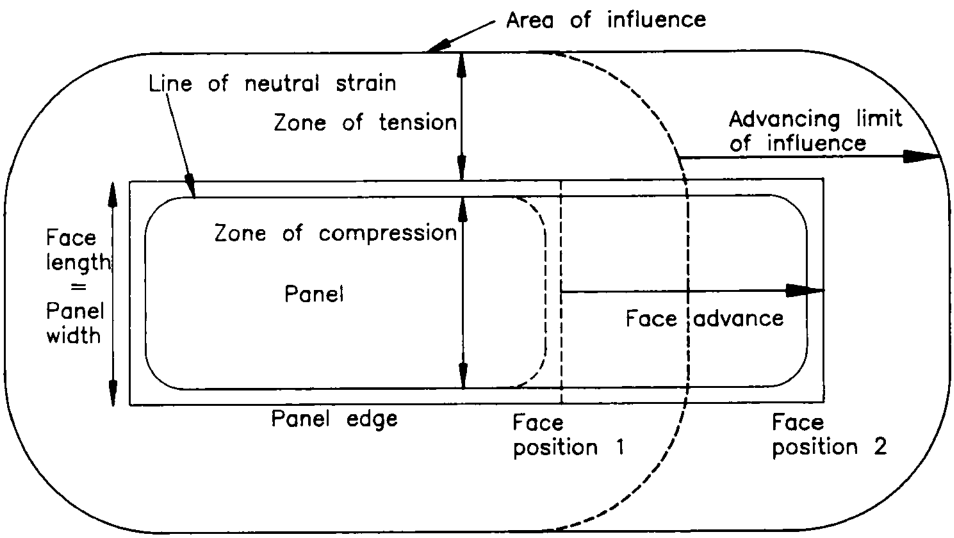
Subsidence from longwall mining occurs in the form of a wave moving parallel to and at the same rate as the line of the advancing coal face (Figure 3.3). Most of the subsidence is transmitted to the surface in a relatively short period of time depending on the depth of the seam and the characteristics of the overlying strata, but residual subsidence may occur up to 2 years after mining has taken place. The subsidence produced is fairly regular and can be accurately predicted.

The surface subsidence develops with various components of movement each with its own effects on surface structures:

- **Vertical or displacement subsidence:** This may have little effect on structures providing it is uniform but may have a significant effect on rivers and lowland drainage by inhibiting the rate of flow and increasing flood potential;
- **Tilt or differential subsidence:** This may affect building structures of which tall structures would be the worst affected.



(a) Section showing advancing longwall face



(b) Plan showing advancing longwall face

Figure 3.3: Longwall workings (after Waltham, 1989[250])

Tilt can have a significant effect on canals, land drains, pipelines and sewers causing blockages and flooding. Bridges and long buildings may also be affected;

- **Ground strain:** This is developed as tension over the crest of the subsidence wave and compression over the trough, with horizontal displacement reaching a maximum in the wave centre. Ultimate strain, which is the sum of tension and compression, is typically several mm/m, and causes the majority of building damage, with long terraces of houses often being the worst affected.

Provision is generally made for repairing any subsidence damage resulting from new mining operations. Subsidence effects due to longwall mining can be predicted accurately by subsidence engineers.[171, 257]

3.2.6 Shafts

Shafts provide vertical access to the workings. Shaft size and depth varies, but modern shafts may be as much as 8m diameter and greater than 1000m deep. Shafts are often circular, but can also be oval, square or rectangular. Linings of timber, brick, stone or concrete are generally provided except in strong rock were a lining may not have been considered to be necessary. Most disused shafts have been wholly or partially filled and may be concealed at the surface.

Subsidence can occur due to the sudden collapse of the shaft and a crater is generally formed at the surface as material slips into the shaft (see Photograph 3.3 and Figure 3.4). The size of the crater depends on the diameter of the shaft, the depth to bedrock and the angle of repose of the surrounding material.

Shaft collapses will occur due to:

- deterioration and collapse of the shaft lining;
- settlement or degradation of the fill material within the shaft;
- the collapse of staging within a partially-filled shaft.

The shaft collapse may occur naturally or can be triggered by factors such as:

- marked changes in groundwater levels due to extremes of weather, or due to soakaways or burst water mains;
- dumping of materials near or above shafts;
- vibration from plant or traffic;
- blasting and seismic shocks;
- mining subsidence.

In some cases collapse may occur slowly leading to a gradual loss of support and worsening damage to nearby structures. However, there is a risk of sudden collapse occurring in some instances which may have a catastrophic effect on structures, roads and utility services and will thus present a serious safety hazard.

Photograph 3.3: Collapsed mineshaft (source: Richards, Moorehead and Laing Ltd)

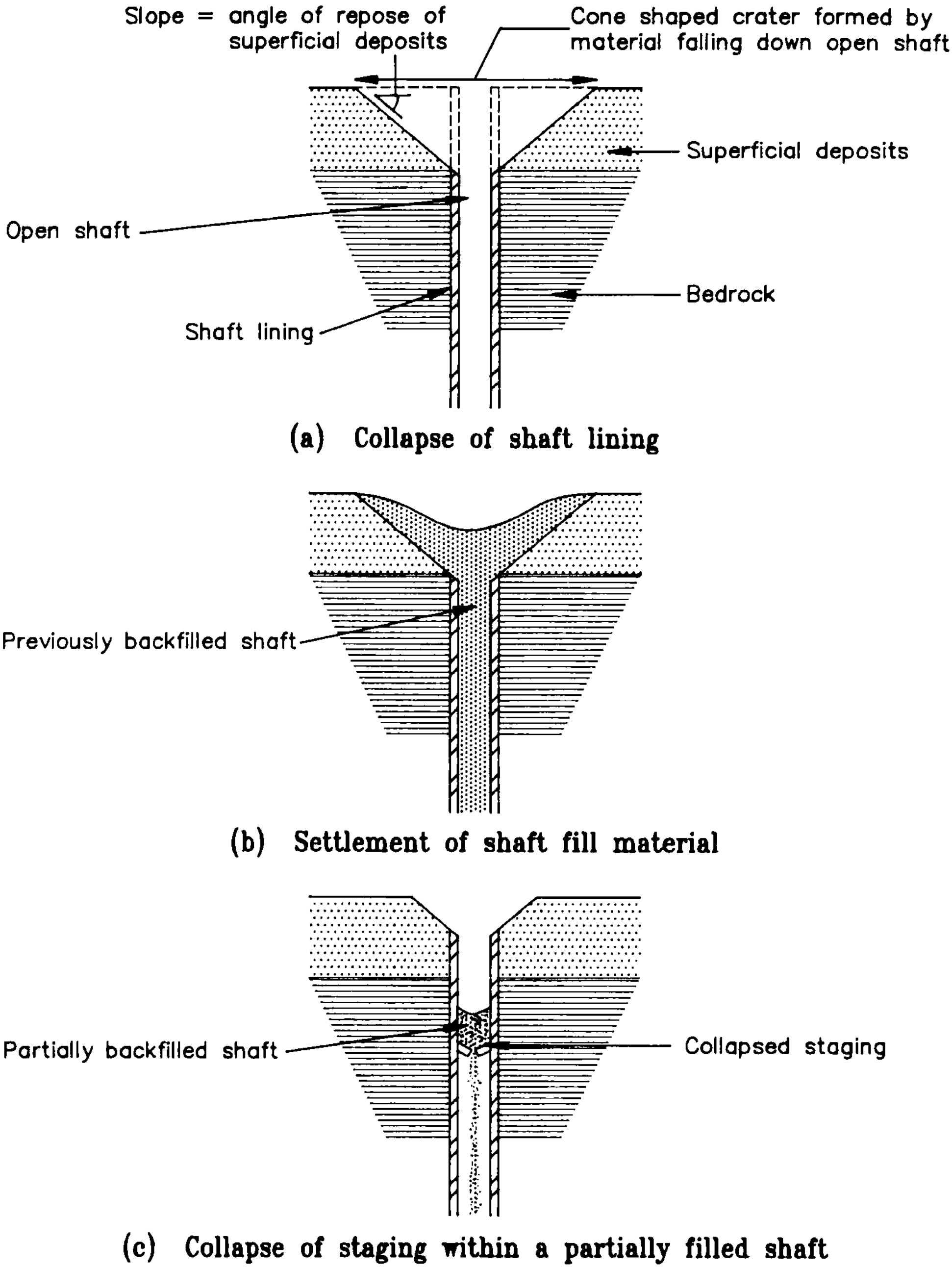


Figure 3.4: Shaft collapses

3.2.7 Adits

Adits provide horizontal or inclined access to the underground workings. Adit size varies, but a brick, stone, concrete or timber portal is normally provided and the adit is lined until competent rock is reached. The mouth of a disused adit may be concealed if the portal and roof near the entrance has collapsed.

Subsidence may occur due to the sudden collapse of the ground around the entrance to the adit. Collapse will take place due to:

- deterioration and collapse of the adit portal or tunnel lining;
- collapse of the fill material and stopping placed within the adit.

An adit collapse may be triggered by factors similar to those which could cause a shaft collapse (see Section 3.2.6).

Subsidence caused by the collapse of an adit is generally fairly localised and is usually less serious than a shaft collapse. However, subsidence damage may still be caused to nearby structures.

3.2.8 Opencast mining

Opencast mining involves the removal of the overburden to allow coal to be worked by surface mining methods. For coal workings the open pit is normally progressively filled as work proceeds, and the site is then restored. In some instances opencast coal workings have taken in and reclaimed former derelict areas from older underground workings (see Section 17.2.2).

Subsidence inevitably occurs on opencast sites due to settlement of the often considerable depth of backfilled material which is usually placed without being compacted. Such settlement of restored opencast sites is likely to continue for several years.[53]

3.2.9 Subsidence damage to structures

The effects of subsidence damage to structures and civil engineering works is discussed in the following paragraphs.

Buildings

The response of building structures to mining subsidence can be assessed, but is difficult to predict with accuracy. The likely behaviour of a structure will depend on several factors. The most important of these are:

- the size, shape and orientation of the structure in relation to the underground mine workings;
- the foundation design and type of superstructure;
- the methods of construction and quality of materials used;
- the age of the building and standard of maintenance and repair.

The first signs of subsidence damage may be the appearance of cracks, doors and windows becoming ill fitting, or floor tiles becoming loose and heaving. Damage may become progressively worse leading to severe cracking in some cases and possibly to eventual collapse. In the event of the collapse of a shaft or shallow workings, damage will occur more suddenly.

Roads

Subsidence damage to roads may occur as follows:

- distortion of horizontal and vertical alignment;
- fracturing and distortion of road foundations;
- undulations in the running surface;
- damage and displacement of kerbs, channels, flagging and fences;
- disruption of drainage and consequential flooding due to surface settlement;
- consequential damage *e.g.* water action from fractured mains.

The formation of local changes in gradients on high speed roads may result in a safety hazard. Disruption to drainage may cause problems from ponding in some cases.

Railways

Subsidence damage to the running track may occur as:

- distortion of horizontal and vertical alignment;
- disturbance to the track bed;
- undulations in the track bed;
- disruption of drainage with consequential flooding.

Restrictions may be imposed on traffic until remedial works are carried out.

Bridges

Bridge piers or supports can experience movement towards or away from each other which may affect the bridge bearings. Tilt or twist may have a serious effect on bridge decking. Bridge arches may also be affected and flattening of the arch may occur in some cases.

Canals and rivers

Canals and rivers affected by subsidence may require remedial works to:

- raise bank levels;
- raise weir levels;
- seal leaking banks;
- raise bridge levels;
- repair locks and culverts.

Drainage

Subsidence may result in a loss of gradient in drainage pipes with resulting blockages or lack of capacity. Cracked or broken pipes may also occur in some cases.

Utility services

Underground water, gas, electricity and telephone utility services may be disrupted as a result of subsidence damage. Overhead electricity lines and pylons may also be affected.

Colliery spoil heaps

Mining subsidence can have a destabilising effect on some tips (see Chapter 6).

3.3 Investigation of mine workings

3.3.1 Requirement for investigation

On development sites where there is a possibility of past mining having taken place, an archival search should first be carried out of available data. If the information collected suggests that mine workings are present, a mining investigation will be necessary. A mining investigation will also be necessary in cases where damage has occurred to structures and mining subsidence is the suspected cause. Figure 3.5 shows a flow diagram for the investigation of a site potentially affected by mine workings. Such an investigation should be planned by a specialist consultant. The following sections describe the various stages of the investigation and the methods which are employed.

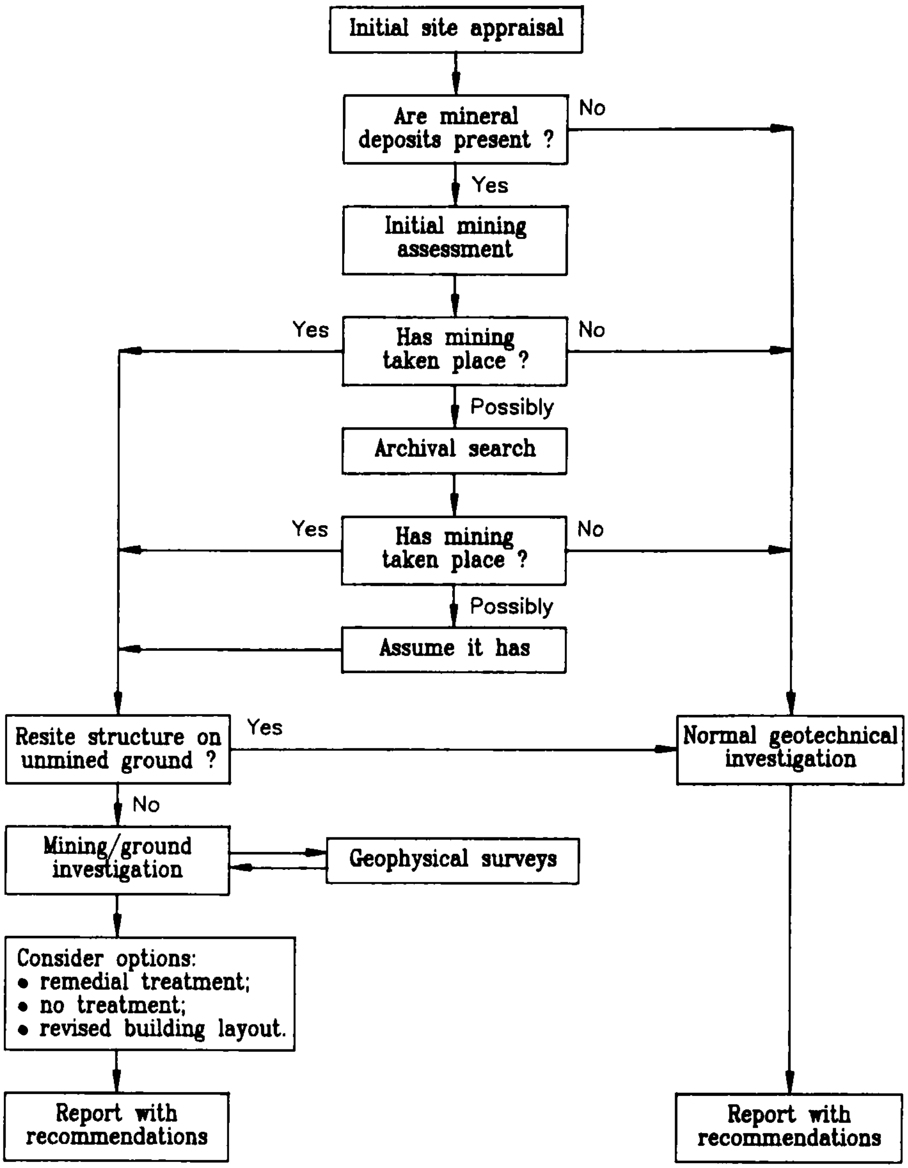


Figure 3.5: Flow diagram showing the general procedure for assessment and investigation of a site potentially affected by mine workings (from Healy and Head, 1984[114])

3.3.2 Archival search

Sources of information vary from site to site. The following are likely sources of information:

- mining company records;
- local authority records;
- geological survey records;
- old topographical maps;
- aerial photographs;
- local mining specialists;
- local inhabitants.

A lack of information on past mining activities does not necessarily mean that no mining has taken place. In areas with a long history of industry and development it is reasonable to assume that any accessible coal seams or mineral veins have been worked.

3.3.3 Walk-over survey

A visit should be made to the site to verify, as far as possible, the information collected in the archival search. Any visible evidence of mining should be noted. Such evidence may appear as spoil heaps, crown holes, shafts, surface workings, and remains of mine structures.

3.3.4 Desk study

From the available information it may be possible to assess the extent, type and date of any mining activity and to determine the presence or possible location of any shafts, and whether there is a history of subsidence on the site.

Plans should be produced to show the following information:

- the location and depth of mineral deposits, details of whether these deposits have been mined and the mining methods employed;
- the locations or approximate locations of known or suspected shafts;
- visible signs of mining activity such as spoil heaps, crown holes and bell pits. Details of any ground subsidence and settlement damage to buildings;
- zones of possible development constraint due to mining activity should be plotted *i.e.* parts of the site where development cannot be carried out without investigation and necessary remedial treatment.

3.3.5 Mining investigation

The object of the mining investigation will be to obtain all or some of the following information, depending on the individual circumstances:

- site geology, including details of ground strata;
- geotechnical properties for foundation design;
- presence or absence of shallow workings and the condition of any workings present;
- the location and condition of any shafts and adits;
- details of the groundwater regime.

3.3.6 Investigation techniques for mine workings

Direct investigation methods will normally need to be employed using boreholes, drillholes, trial pits or trenches, or a combination of these techniques. Indirect investigation methods may be useful to provide preliminary information and reduce the amount of direct investigation required. Investigation techniques are discussed in Section 2.5.

Indirect methods

A number of geophysical methods are available, but specialist knowledge is required to interpret survey results as anomalies and patterns can be difficult to discern.[157]

Geophysical methods which may be appropriate include the following (see also Box 2.7):

- electrical resistivity;
- magnetometry;
- electro-magnetic surveys;
- seismic surveys;
- ground probing radar.

Geochemical investigation by the sampling of soil gases can be used to indicate the presence of coal workings or a shaft.[213] However, methane may be present in the ground for other reasons *e.g.* as a result of the anaerobic degradation of waste materials, but it is possible to differentiate between methane from different sources by analysis of other gases. The simultaneous presence of carbon dioxide and volatile organics *e.g* volatile fatty acids (VFAs) is thus indicative of landfill gas rather than mine gas (see also Section 11.2.4).

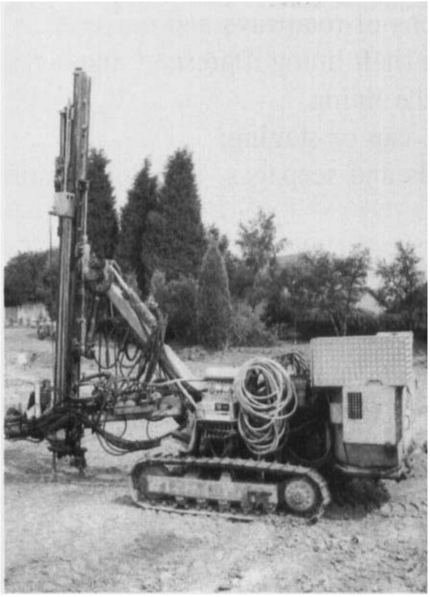
Box 4.3 provides more details on methane associated with abandoned mine workings.

Direct Methods

Direct investigation methods are more expensive than indirect methods, but generally provide more reliable information. The methods usually employed are:

- **Trial pits and trenches**: Trial pits and trenches can be used to investigate shallow ground conditions, to determine the effects of subsidence, and to locate shafts, adits and other features.

- **Boreholes:** Drilling is the method most commonly used for investigating underground workings, and rotary-percussion drilling is the quickest and least expensive method using water flush or sometimes air flush (see Photograph 3.4). Monitoring of water returns provides information on rock type, state of fracture and whether voids are present. Rotary-core drilling will be appropriate where core samples are required. The use of close circuit television downhole cameras can be used to check the condition of underground voids. The depth and spacing of boreholes should be subject to advice by a specialist consultant and will vary depending on site conditions and the type of development proposed. A depth of 30m and a staggered grid spacing of 5m or less is appropriate for investigating shallow workings beneath a proposed building development. Where the strata dips steeply, inclined boreholes are likely to be required.



Photograph 3.4:
Investigation of shallow workings using rotary-percussion drilling (source: NKC Geotech Ltd)

3.4 Investigation of shafts and adits

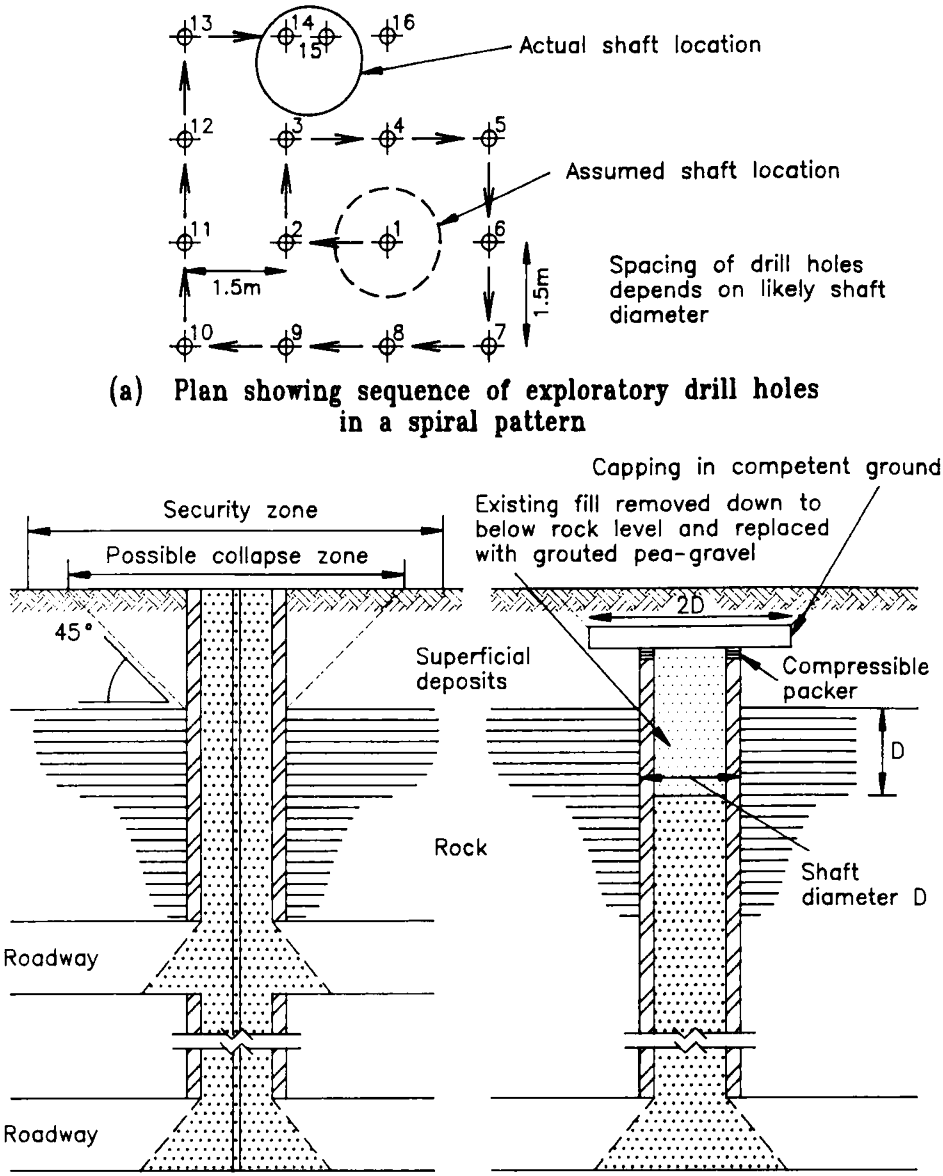
3.4.1 Shafts

Investigation of shafts by trial pitting and trenching is the method most commonly used when the depth to rockhead is shallow *i.e.* up to 5m. Drilling will be required where the depth to rockhead is greater or where the shaft is located close to existing features which cannot be disturbed. The most efficient method is to drill in a spiral pattern working outwards from the assumed shaft location (Figure 3.6(a)). Drilling will be required at close centres of around 1.5m, or greater for larger shafts. Once the shaft has been located the following information should then be obtained by further investigation involving drilling and trial pitting within and adjacent to the shaft:

- shaft size and shape;
- depth to rockhead and details of superficial deposits;
- type and condition of fill material if present, and whether the shaft is fully or partially filled;
- in an open shaft, the locations of roadways and culverts;
- the type and condition of the shaft lining if present, and details of any fill material behind the lining;
- details of any existing plug, cap or staging;
- details of groundwater levels and seepages, and any existing drainage provisions;
- results of gas monitoring.

3.4.2 Adits

Investigation of adits is generally carried out by excavation. Drilling is appropriate in some cases *e.g.* where the adit has subsequently been covered with a significant depth of fill material, or where the adit is



(b) Drilling and progressive grouting of existing shaft filling (assuming filling is suitable)

(c) Plugging with grouted pea-gravel in conjunction with capping in competent ground

Figure 3.6: Shaft location by drilling and shaft treatment by grouting

located close to existing features. Once the adit has been located the following information should be sought:

- adit size and shape;
- inclination of adit;
- type and condition of adit portal if still present;
- type and condition of tunnel lining where provided;
- depth to rockhead and details of superficial deposits;
- condition of strata overlying the adit;
- details of any existing stopping or filling;
- details of groundwater levels and seepages, and any existing drainage provisions;
- results of gas monitoring.

3.4.3 Safety precautions

Extreme care is required when investigating concealed shafts as these can be subject to sudden collapse when the fill or support staging is disturbed. Adits or shallow workings may also collapse during investigation, although this is generally less serious than the collapse of a shaft. A fenced security zone should be established around the investigation area. This area should extend beyond the potential collapse zone, which is assumed to be a cone projecting upwards with sides at an angle of 45° from the point where the walls of the shaft intersect rock head (Figure 3.6(b)).

All personnel involved in the investigation should be equipped with harnesses and safety lines secured to anchorage points at least 5m outside the collapse zone.[172] Plant and equipment should also be tethered to anchorages at least 10m outside the collapse zone. Suitable anchorages are steel posts concreted into boreholes.

There is a risk of explosion if mine gas is present, therefore continuous gas monitoring should be carried out during the investigation of shafts, adits and shallow workings. Sources of possible ignition should be prohibited within the security zone *e.g.* smoking, naked flames, spark ignited engines, or electrical apparatus which is not flameproof. Specialist guidance should be sought from a mining ventilation engineer regarding precautions required to deal with gas emissions during shaft treatment.

3.5 Treatment of shallow workings, shafts and adits

3.5.1 Options for treatment

Treatment methods for shallow workings, shafts and adits are well documented.[72, 114, 172, 250]

Construction in areas of shallow workings *i.e.* less than 30m depth, generally requires some form of treatment to consolidate the workings, followed by the use of appropriate foundations to support structures.

Treatment is generally carried out to fill open or partly filled underground cavities and prevent upwards migration of voids which may lead to subsidence damage. Fully collapsed workings are likely to require treatment in order to improve the bearing characteristics of the ground.

Depending on the site conditions, treatment is not normally necessary where there is cover of 20m of competent rock above the workings. A minimum rock thickness of 15m or 10 times the seam thickness, whichever is greater, is a rule sometimes applied in the UK. However in unstable conditions treatment of workings to depths in excess of 50m may be required.

The main treatment options are as follows:

- excavation through the shallow workings and backfilling with suitable material compacted in layers. This method is normally only suitable for shallow depths up to 5m below ground level;

- partial grouting either to improve the bearing characteristics or reduce the risk of void migration;
- full grouting of mine workings and possibly overlying strata to improve overall ground-bearing characteristics.

Where grouting is to be carried out the grout pressure should be carefully controlled in order to avoid the risk of ground heave occurring at the surface.

In some cases treatment may be required to deal with shallow workings discovered beneath existing structures.

3.5.2 Grouting of open workings

Grouting is generally carried out using a mixture of cement and pulverised fuel ash (PFA), or cement, PFA and sand in varying proportions depending on the circumstances. Pea gravel infilling may be used to limit grout travel within open workings. Grout is injected via grout tubes of approximately 25mm diameter inserted into drill holes of 50 to 75mm diameter drilled on a grid pattern (Figure 3.7). Grout pressures should not normally exceed 10kN/m^2 per metre of depth. Grouting continues until the specified pressure is reached. The grout tube is then partially withdrawn until the pressure drops and further grout can be injected. The grouting procedure continues until the grout reaches the top of the drillhole. Where the specified pressure cannot be reached, re-drilling after 24 hours and further grout injection may be necessary. Records should be kept of the grout take at each drill hole.

Grouting is normally carried out to a boundary located well outside the proposed building area. In order to limit the quantity of grout injected into workings, a perimeter wall of grout is provided around the edge of the treatment area using viscous grout injected into pea gravel. Perimeter drill holes may be 75 to 100mm diameter to accommodate the pea gravel,

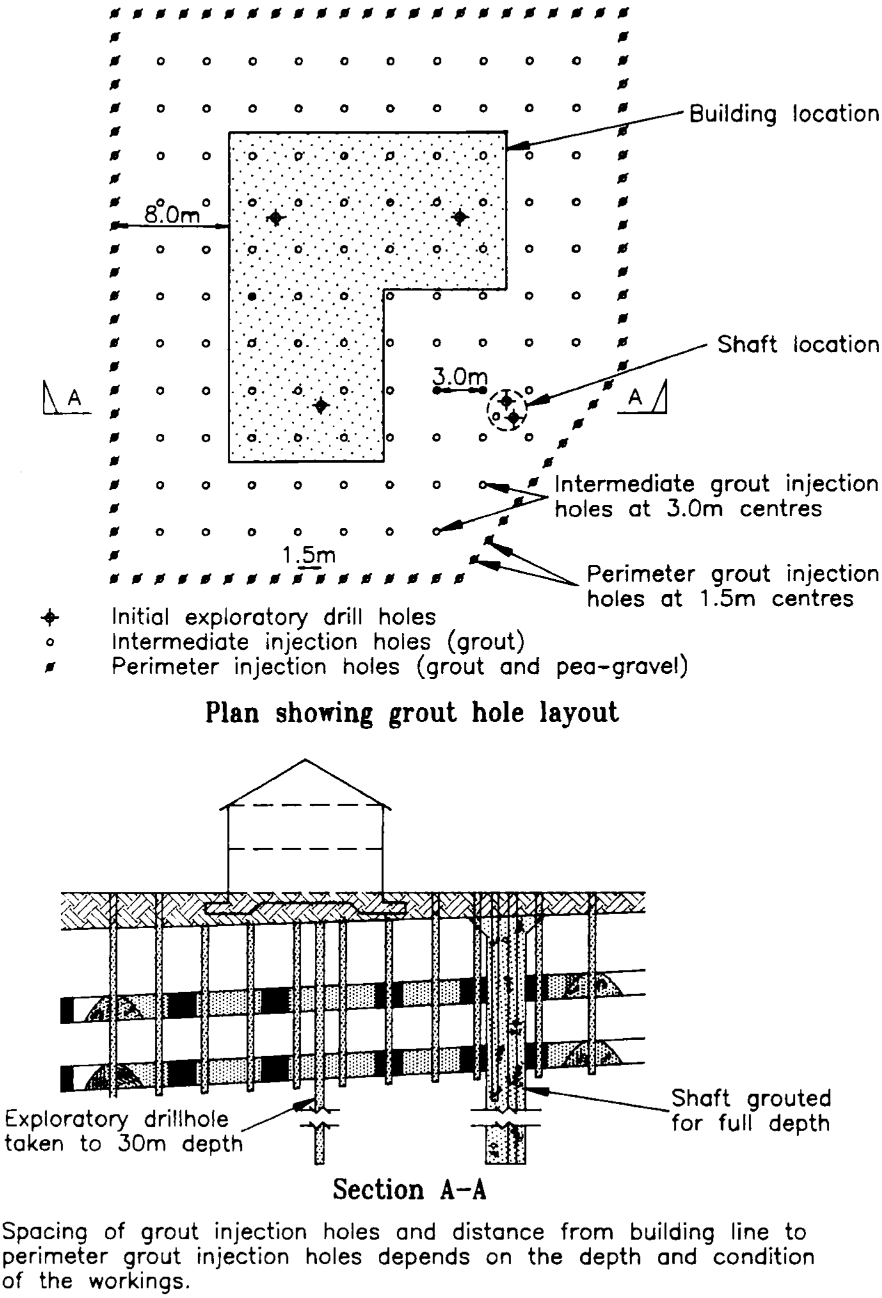


Figure 3.7: Grouting of open shallow workings

and spaced at 1.5 to 3m centres. Typical drillhole centres for infill grouting are 3 to 6m, although closer spacing may be required in areas of high grout take.

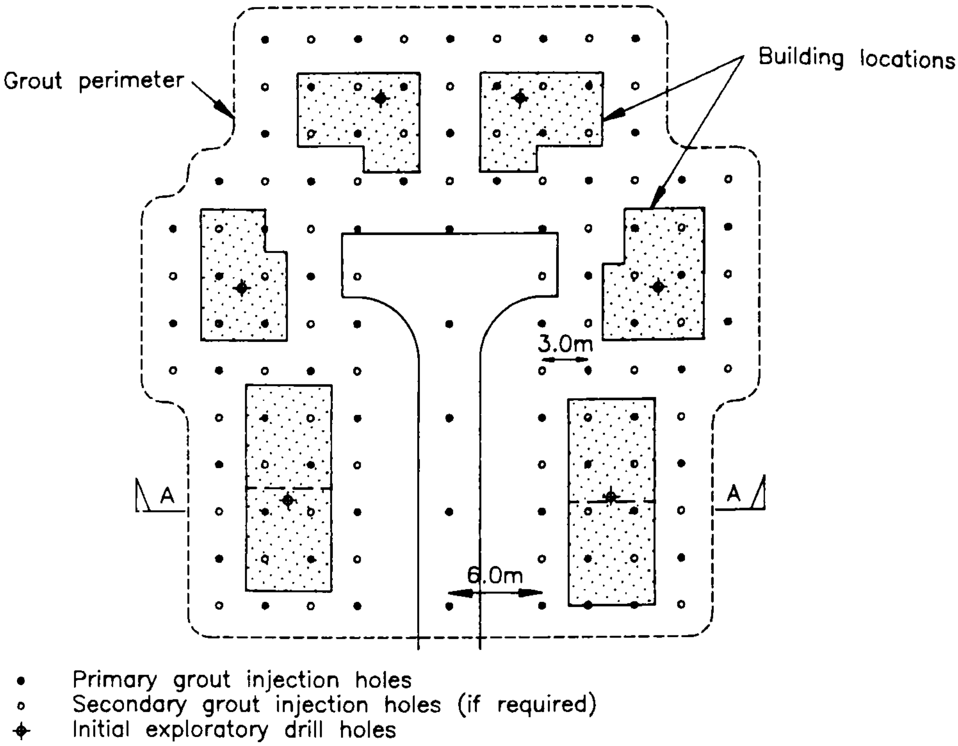
3.5.3 Grouting of collapsed workings

Grouting of collapsed workings is carried out in a similar manner to that described for open workings, although a perimeter wall is not normally required. Treatment of collapsed workings is less straight forward than for open workings in that void locations are more difficult to predict. Grouting is carried out from primary holes at approximately 6m centres. If required, secondary infill holes may be drilled at 3m centres (Figure 3.8). If voids are discovered these may require individual treatment. Re-drilling and further grouting will be necessary in areas where the specified pressure cannot be reached or the grout take is excessive.

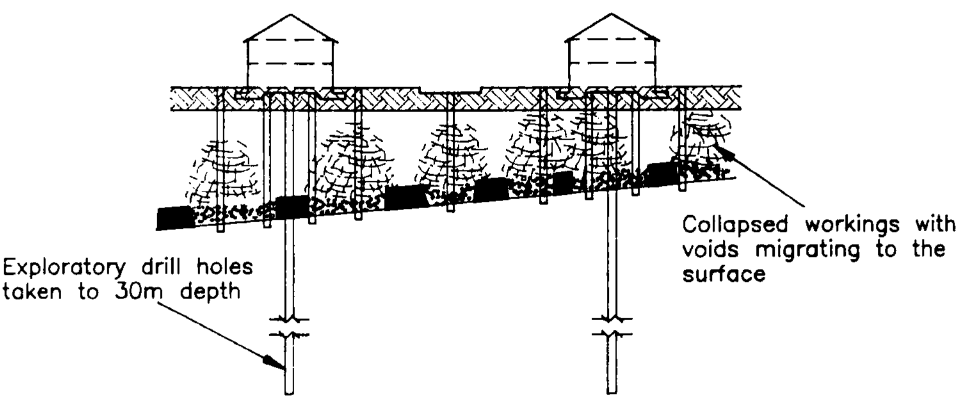
3.5.4 Treatment of abandoned shafts

The choice of shaft treatment method depends on a number of factors including:

- available funding;
- depth to rockhead;
- size of shaft;
- condition of existing lining;
- whether the shaft is open or filled;
- location and proximity to existing structures;
- proximity to urban areas;
- whether future access is required by authorised persons or wildlife *e.g.* protected species such as bats.



Plan showing grout hole layout



Section A–A

Figure 3.8: Treatment of collapsed shallow workings

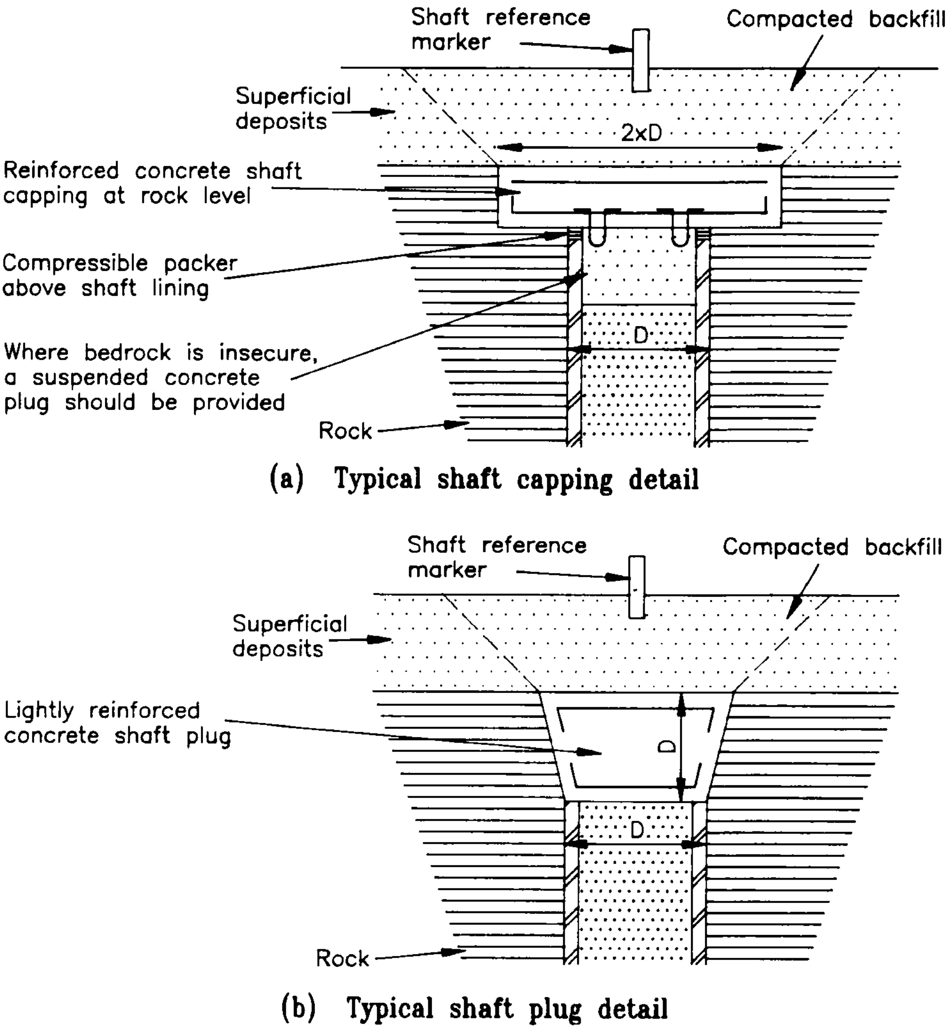
Methods commonly used to ensure the security of shafts are as follows:

- capping using reinforced concrete;
- plugging with reinforced concrete;
- filling and plugging with grout;
- drilling and grouting;
- provision of prefabricated steel or concrete covers;
- filling in conjunction with security fencing and warning signs;
- security fencing and warning signs only.

Capping

Capping with reinforced concrete is the most common method of shaft treatment (see Photograph 3.5). The cap should ideally be located at or below rockhead (Figure 3.9(a)) and the width of the cap should normally be at least twice the shaft diameter. The cap thickness and reinforcement requirements will depend on the shaft diameter, the depth of overburden

Photograph 3.5: Capping of a mineshaft (source: Richards, Moorehead and Laing Ltd)



Notes:

1. Capping or plug to be designed to support overburden plus imposed loading of $33kN/m^2$ at cap level.
2. Concrete to be at least grade $30N/mm^2$ made using sulphate-resisting cement.
3. Where mine gas is present, surface of capping or plug to be provided with membrane or clay seal. Alternatively, gas venting with a flame arrestor is to be provided.

Figure 3.9: Shaft capping and shaft plugging (after UK National Coal Board, 1982[172])

and any surcharge loading. Where accumulation of gas may occur venting should also be provided. A provision for drainage may be necessary in some circumstances.

If personnel access is required, an access shaft of precast concrete manhole rings with a lockable cover may be provided down to cap level. In some cases a grilled access may be required *e.g.* for wildlife such as bats, or to maintain existing ventilation levels. Where the shaft capping is to be covered, a location marker such as a concrete post or stone plinth should normally be provided at the surface. When the shaft cannot be capped at bed rock due to excessive depth or limited access then it is acceptable to cap the shaft in competent ground at a higher level provided the existing shaft lining below cap level is in a stable condition. Compressible packing 50 to 75mm thick should be provided between the underside of the cap and the top of the shaft lining. In some cases it may be necessary to fill the shaft and grout the fill down to just below bedrock level (Figure 3.6(c)).

Plugging

Plugging using reinforced concrete may be appropriate for small shafts up to 3m in diameter in situations where access is limited (Figure 3.9(b)). The plug would normally be installed at rock head and the rock should be trimmed back to provide a stable keyed surface. The provision of gas venting or personnel access would be as described earlier for capping.

Filling and plugging with grout

When the depth to rockhead is excessive, or when access is limited, it may be necessary to fill the shaft with granular material and provide a plug by grouting the fill down to just below rockhead. For shafts which are already filled, unsuitable fill should to be removed down to rockhead and replaced with granular material prior to grouting.

Drilling and grouting

Drilling and grouting may be required in situations where buildings are to be located above a shaft (Figure 3.7), although building close to shafts, whether treated or untreated, is not normally recommended. Grouting may also be required for a shaft discovered to be present beneath or close to an existing structure. The existing shaft filling should be investigated by drilling prior to grouting operations.

Prefabricated steel or concrete covers

This method is appropriate for existing shafts which are to remain open and where bedrock is close to the surface, or where the existing lining is in a stable condition. Personnel access or grilling may be provided through the cover as necessary.

Filling, in conjunction with perimeter fencing and warning signs

Shaft filling and fencing is an appropriate form of treatment in open country away from populated areas. Filling of large shafts would normally be carried out using suitable granular material tipped into the shaft in a controlled manner by means of a conveyor. Free draining single size fill material should be used in the lower part of the shaft where existing mine drainage systems have to be maintained. Where shafts are already filled, investigations should be carried out by drilling to determine whether the shaft is fully or only partly filled. If voids are discovered within the shaft below a platform or obstruction it will be necessary to fill the void using an appropriate fill such as pea gravel.

The shaft filling is likely to be subject to settlement, and may require topping up at a later date. As the shaft may not be properly stabilised by filling alone, the provision of security fencing and warning signs is also recommended.

Security fencing and warning signs only

The provision of security fencing and warning signs is only acceptable as a short term safety measure, and should not be considered as a long-term solution. The fencing should be located outside the cone of failure which may be formed should the shaft collapse.

3.5.5 Treatment of adits

The choice of adit treatment method depends on:

- available funding;
- location and proximity to existing structures;
- condition of existing portal;
- condition of existing lining, if provided;
- whether the entrance to the adit has collapsed;
- depth to rockhead and the condition of strata, overlying the adit;
- requirements for drainage or gas venting;
- whether future access is required for authorised persons or wildlife *e.g.* protected species such as bats.

Methods normally used to treat adits are as follows:

- stopping with filling and grouting;
- stopping only;
- grilling;
- excavation and backfilling;
- drilling and grouting.

Stopping with filling and grouting

Adits are normally treated by stopping and filling to prevent subsequent collapse leading to subsidence at the surface. A stopping of brickwork, concrete or grouted fill should be provided which is capable of withstanding the pressure from infill material or grout. The stopping should be located at a suitable distance down the adit to ensure an adequate depth of rock cover of at least 10 times the tunnel height above the remaining length of untreated adit. The length of adit between the stopping and the entrance is then backfilled with suitable fill. The fill may be progressively grouted either from within the adit or from the surface. The entrance to the adit should be faced with a wall of brick or concrete. Provision should be made through the filling for drainage or gas venting as necessary.

Stopping only

Assuming the adit is considered to be stable, in some circumstances it may be appropriate to close the adit by the provision of a brick or stone wall at the entrance. A lockable door may be included within the wall if access by personnel is required.

Grilling

Where continued access is required to the workings for birds and mammals, or where existing ventilation needs to be maintained, a steel grille offers the best solution providing the roof of the adit is stable. A lockable gate may be included in the grille.

Excavation and backfilling

This method of treatment may be used for shallow lengths of adit where the depth below ground level is less than 5m.

Drilling and grouting

Drilling and grouting may be used to stabilise lengths of open or collapsed adits in situations where access is difficult due to the proximity of nearby structures.

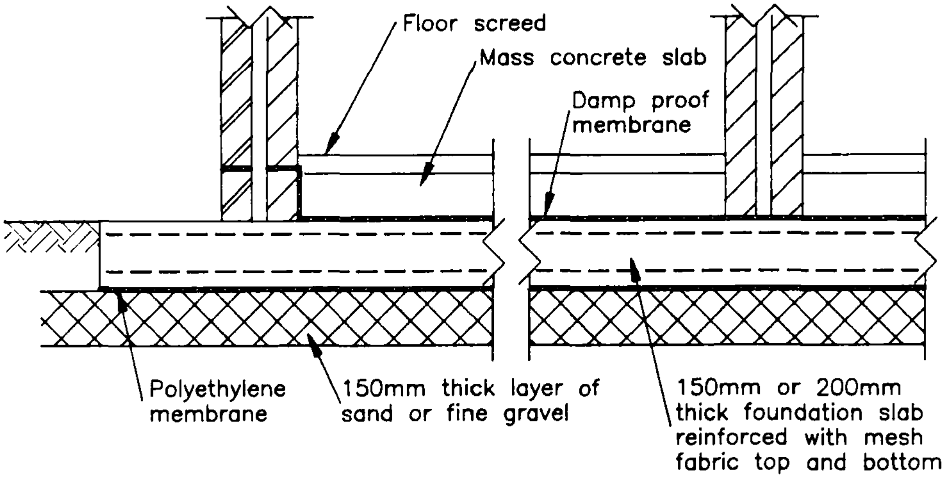
3.6 Methods of minimising subsidence damage

3.6.1 New structures affected by contemporary longwall workings

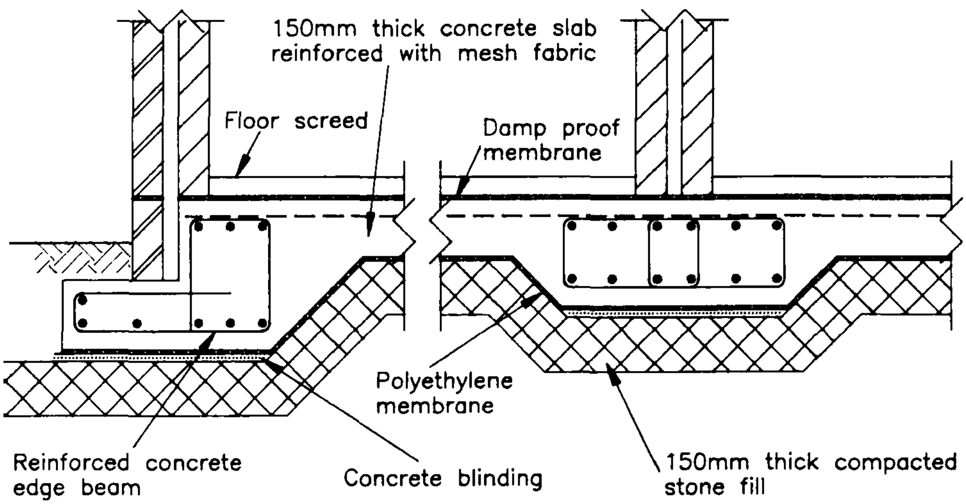
Where mining subsidence from longwall workings is expected, special precautions should be taken in the design of the building foundations and superstructure.[126, 240, 257] Buildings should be designed, as far as possible, to be flexible. Shallow, flexible raft foundations with a smooth underside constructed on polyethylene placed over a 150mm thick layer of sand provides good protection against tension and compression strains at the ground surface (Figure 3.10(a)). The raft foundation should be constructed close to the ground surface to avoid problems due to the effects of side thrusts. An alternative method is to use reinforced strip or pad foundations laid on a layer of sand. A space should be provided at the ends of the foundation trenches which is then filled with compressible material. The construction of basements should be avoided. Large structures should be divided into independent units by means of construction joints passing through the structure and its foundations. For multistorey structures, foundations consisting of pad and beam construction, or cellular rafts are required. Where large movements are expected, provision should be made for jacking to allow the structure to be re-levelled. Buildings should not be constructed close to the surface locations of geological faults.

Special flexible building structures have been developed for use in mining areas *e.g.* the CLASP system used in the UK for many school and office buildings.[29] This system involves the use of a pin jointed steel frame with diagonal bracing between column locations which incorporates compressive springs capable of resisting wind loading but designed to distort when ground settlement occurs.

Drains should be provided with ample falls to ensure that they will continue to operate after any reductions in gradients. Pipes should be bedded in granular material, and double joints should be provided to



(a) Section showing typical flat raft foundation for housing subject to subsidence from longwall workings



(b) Section showing typical semi-raft foundation for housing subject to differential settlement

Figure 3.10: Raft and semi-raft foundations (after Tomlinson *et al.* 1978[240], redrawn by the permission of the Controller of HMSO)

allow articulation to occur at manhole positions and entry to structures. Manholes, should be constructed of precast concrete rather than brick for greater strength.

Roads should be of flexible macadam construction rather than more rigid concrete construction. Bridges should be designed to articulate with movement joints provided within the structure. Jacking points may be required to allow re-levelling to be carried out.

Service installation should be designed to accommodate ground movements.

3.6.2 Existing structures affected by contemporary longwall workings

Subsidence damage to existing structures can be limited by the use of appropriate preventative measures. Trenching, for instance, may be provided around buildings to reduce damage from horizontal strains, and damage to long buildings can be reduced by splitting them into smaller units with the incorporation of movement joints.

Buildings of special importance can be protected by the provision of special foundations incorporating jacking facilities. Temporary internal propping may also be provided in some cases. Surface subsidence effects can be reduced by using partial extraction methods, with support pillars being left in place beneath sensitive sites. The use of backstowing to reduce surface subsidence is sometimes carried out by backfilling the workings behind the longwall face.

Drains should be modified or relaid to provide adequate falls with flexible connections. Service installations may need to be modified, and frequent inspections should be carried out to check for damage.

3.6.3 New structures affected by abandoned mine workings

Different techniques are required to protect structures to be built above abandoned shallow workings. Following a mining investigation, treatment would normally be carried out to stabilise the workings beneath the proposed development and prevent the collapse of any nearby shafts and adits. Raft or semi-raft foundations would then be provided to minimise the effect on the superstructure of possible differential settlement. The foundations should be designed to span or cantilever over possible areas of reduced bearing capacity. A typical semi-raft foundation for use in low rise buildings is shown in Figure 3.10(b). The building type, the location on the site and the foundation solution adopted should be chosen to suit the mining conditions and the extent of stabilisation treatment carried out. Where possible, major structures should be located outside the area known to be affected by shallow workings. Alternatively the foundations to major structures should be taken below the level of the workings using deep excavation or piling. However, care should be taken when using piling to ensure that the piles are founded in competent strata below the level of any workings. Structures should if possible, be sited away from shaft locations even when the shaft may have been treated.

3.6.4 Existing structures affected by abandoned mine workings

Where existing structures have been affected by the collapse of abandoned workings, investigation and treatment will be required to stabilise the workings and deal with any shafts and adits. Underpinning of the existing foundations may be required followed by remedial works to the superstructure. Investigation and treatment of the workings may be constrained by the need to avoid further disruption to the existing structure.

3.6.5 Highway construction over abandoned mine workings

Where investigation of shallow workings indicates that there is a risk of instability, it is normal practice to stabilise the workings by grouting. An alternative approach which has been adopted is to use a geotextile reinforcement incorporated into the road formation which is designed to span over any voids caused by crown holes in order to keep the deformation of the road surface within acceptable limits.