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TREATMENT OF ABANDONED MINE SHAFTS AND ADITS

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PREFACE

This technical note has been prepared specifically for the information and guidance of those engaged in the examination, design, and construction of works connected with abandoned mine entrances. It is assumed that the charge of such works will be entrusted to engineers and technicians who are trained. It is also assumed that the day to day execution of works will be carried out under the direction of appropriately experienced personnel.

There are many old mine workings of various kinds, some dating from the 19th century. Many are unrecorded, with no evidence of their existence. Even after new mining regulations were enacted, it was not until comparatively modern times that acceptable standards were reached in the completeness and accuracy of the records.

Problems and hazards caused by old shafts and adits include

- subsidence;
- failures of old shafts which have been inadequately filled or otherwise treated;
- persons gaining unauthorized access;
- fires;
- emission of mine gases;
- runoff water entering old mine and discharging polluted water elsewhere;
- trash dumps and vermin infestation.

This technical note has accordingly been compiled using current knowlege of methods of treating mine entrances to make the surface stable and secure. The subject matter is divided into four parts as follows:

General
Design
Operations
Appendix A: Technical Considerations

As there are many more shafts than adits and shafts give rise to far more concern, the technical note generally uses the word "shaft" even when it may have an application to adits. Specific reference to adits indicates that the subject matter is confined to them. The term "adit" includes any walkable outlet from the surface into the mine workings. The word "entrance" is used where the context requires an inclusive term.

This technical note is adapted from a document originally developed by the National Coal Board, London, England. While most of the terminology has been revised to "American" English, some portions or phrases may still have an "English" connotation.

Chapter 1 - GENERAL

OBJECTIVES OF TREATMENT

General

Once a shaft has been sunk, it is impossible to restore the earth to its original condition. In the past, entrances were often closed and secured after abandonment by placing a platform or makeshift plug a short distance down the shaft and filling with any available material. In time, these platforms deteriorated and collapsed. Random filling of the whole shaft became more common, but this usually consolidated with time leaving a surface depression.

Random filling steadily improved and has now developed into the process referred to as designed filling. Designed filling cannot be relied on to safeguard the surface absolutely in all cases. It is a practicable solution in most cases if overfill is provided to offset settlement consolidation or a suitable cover is constructed.

Future demand for land may require construction directly over a shaft. Special treatments will be necessary to protect such construction against possible eventualities.

Each case is site specific and must be considered on its own merits, taking into account the proposed future use of the surface.

Objectives of Treatments

The objectives of the treatment may be any combination of the following:

- elimination of surface hazard arising from surface subsidence into a shaft or adit;

- elimination of hazard to existing or future mine workings, or to adjoining mine entrances;

- minimize the escape of mine gases, or provide for release to the atmosphere under controlled conditions;

- prevention of changes in hydrogeology, e.g. the contamination, loss, or mixing of waters in aquifers;

- elimination of continuing maintenance costs;

- facilitate development of the area over or near the entrance;

- retention of an open shaft or connecting roadway for future activity, such as mining, or water supply;

- prevention of spontaneous or man-caused mine fires.

SURFACE CONDITIONS AND HAZARDS

General

Records may or may not be available to give details of entrances whose existence is known or suspected.

Surface Conditions

Many developments, including buildings and public services, have taken place near or over mine shafts and adits and can be expected to be contributing factors in incidents involving serious injury and loss of life and property. The presence of an abandoned mine entrance may be obvious or at the other extreme; it may be completely concealed by fill material or surface development. For the vast majority of abandoned shafts, nothing is known about the condition of the walls, intermediate landings, mine intersections and pit bottoms nor the circumstances of abandonment.

Abandoned shafts which are visible and unfilled to the surface may be enclosed by fencing or walls and provided with a constructed cover to prevent accidental entry. They may have been left open to prevent blockage of mine drainage paths, to monitor water levels, or to serve some later purpose envisioned at the time of abandonment. Waste and refuse dumping is a common occurrence.

Exposed adits normally have brick, concrete, or timber portals with or without actual closures. Concealing may have been accomplished by demolition of the portal, collapsing the roof, and reshaping the surface to conform with the surrounding land. In more recent years, it has been the practice to construct substantial barriers at points where the cover is adequate, filling the passage solid nearly to the surface, breaking in the roof, and finally reshaping the land. Adits are often driven into hillsides, and it is not unusual for water to be discharging through the adit.

Aerial photographs may show evidence of entrances and patterns of shallow mine workings.

Hazards

General.--The main hazards to persons and property on the surface arise from accidental entry, collapse of the surface, gas emission, mine fires, and effects of water.

Accidental entry.-- Accidental entry is a hazard if an old shaft is unfilled from the surface for any depth or if any protective wall, fence, or cap is broken or defective and there is no warning. All abandoned mine workings are attractive targets for trespassers, vandals, and adventurous children. People have been known to put forth considerable effort, including using force, to break through or tunnel under covers and walls in order to reach a shaft or working. Entry through the protective device may be premeditated and deliberate, but falling down a shaft is always accidental. Death or injury can be caused in shafts and mine workings through falling, exposure, starvation, drowning, suffocation, or gas poisoning.

Collapse of ground.--Sudden and complete collapse of the ground is the most dangerous and most frequent type of incident. It generally results from a change in the equilibrium of the shaft fill, the deterioration and failure of shaft linings (often associated with the movement of underground water), a change in the underground situation, increased loading on the surface, or other external disturbances.

Collapse may show as a hole of a size roughly equal to that of the shaft if the lining remains intact or if the walls are solid. More dramatically, if the lining fails and permits loose rock or wet surface deposits to flow into the shaft, a crater with sides sloping roughly at the natural angle of repose of the material will form. The crater radius will correspond roughly to the depth of subsidence. Nearby shafts may be affected in the failure.

Adits usually collapse as general subsidence along the line of the tunnel. Holes may appear at the surface if the overburden subsides into the tunnel.

Any marginal stability may be destroyed by activities such as overloading, shock or movement arising from mining subsidence or blasting, vibration from traffic or machinery, and siesmic activity.

Changes in the ground water table have a particular influence on the behavior of fillings (Appendix A. A.1.1.4). and may cause collapse.

Gas.--Appendix A, Section A.2 generally describes the hazards presented by gas. While methane may be found at some shafts and adits, the possibility is reduced if they have been abandoned for a long time.

Oxygen deficiency can be expected in the lower parts of all shafts, adits, subsidence pits or other mine workings. Each situation requires expert consideration.

Mine Fires.--Mine fires, in addition to the hazard of heat, may leave the surface area thin and incapable of supporting any significant weight. Gases for incomplete combustion may also be a problem.

Water.--The main hazards concerning water are:

- drowning of persons in the shafts;
- deterioration and failure of linings brought about by chemical attack, wet or swelling strata or hydraulic pressures;
- consolidation and movement of fill material;
- settlement of buildings and other improvements with variations in the watertable;
- rapid flooding of mine workings from water in the upper strata or overlying streams and impoundments;
- pollution of aquifers by the mixing of waters from different strata.

Though not specifically within the scope of this technical note, the great threat to active underground mine workings connected to abandoned shafts is always to be borne in mind.

Noticeably more cases of subsidence are reported during long periods of dry weather, or immediately afterwards, when changes in the ground water table are occurring.

Chapter 2 - DESIGN

INFORMATION AND ASSESSMENTS REQUIRED PRIOR TO THE DESIGN OF TREATMENTS

General

This section provides a check list of the information required and assessments to be made in order to determine the best method of treatment for individual cases. The extent to which the information can be obtained will depend on the available records and the accessibility of the shaft.

Details Relating to Mine Workings

Information to be obtained includes:

- geological sections of the strata through which the shaft or adit passes and of the mine workings;

- the general mine plans ,if available, showing seams and the dates of workings, the vertical distance between them and any inter connecting drifts, boreholes, aquifers, barriers, waterlogged areas, areas of methane drainage, and similar information pertaining to adjacent mines which may be relevant;

- large scale plans, if available, that show passageways and voids near the shaft or adit and areas where coal may have been mined to a greater extent than shown on the general plans may indicate materials inadequate to withstand the pressures of the fill within the shaft;

- details of future workings, including strip mining, with an estimate of their probable effects, particularly if the working is to be under the shaft or adit.

Details Relating to the Entrance

Information to be obtained includes:

- relationship and proximity to adjacent shafts and adits;

- public and private utilities at the surface or crossing the site;

- details of type, thickness, and condition of linings, including repaired lengths; information about watertight lining or special construction used in original installation to overcome difficulties with water or weak ground;

- depths of sumps and unissued lengths of shafts below "false" sumps, together with the level of standing water and the details of any pumping operations;

- details of voids formed by connections and openings into the shaft, including level, size, direction and gradient. These will include: cable assemblies, water reservoirs, pump insets, furnace and other ventilation drifts, ventilation widenings at shaft conveyance passing points, exploratory headings, drainage culverts, and entrances to old workings. Care should be taken to search for possible voids hidden behind the shaft lining or covered by deposits of soil or debris. The relative vertical position and general condition of the shaft should be noted;

- details of platforms, furnishings, and equipment in the shaft, drawings being made to fix their locations in the length and cross section;

- details of surface deposits and strata overlying the bedrock;

- samples of strata for strength, and permeability testing in the laboratory from sites selected for plugs, dams or other seals;

- location, quantity and pressure of water infiltrating the shaft, entering directly from the mine workings, including water received from connected mines, leaking dams or barriers, or arriving via faults. The point of appearance of the water may be remote from its source;

- chemical analysis of waters in or surrounding the shaft for their effects on linings and proposed filling materials and in assessment of the effects of the fill on the water. Disposal arrangements for water pumped or overflowing at the surface. Laboratory examination of proposed fill materials;

- presence of gas at various levels, with estimated quantities per millibar fall in barometric pressure, together with any history of effects observed due to changes in barometric pressure;

- potential incentive sparking temperature of strata or coal refuse that may cause fire and proposed fill material;

- mineral rights.

<u>Details Relating to the Surface</u>

- proposed final contours and use of the surface;

- past reclamation conditions of leases and agreements with authorities, purchasers, or other interested parties;

- facilities available for the disposal of mine water discharges.

<u>Assessments to be Made Prior to Selection of Treatment</u>

- Assessments should include: the extent to which areas at the surface may be affected by changes which may occur in the watertable, in particular at other shafts, adits and watercourses, the creation of new or the cessation of existing discharges, and the effects on buildings, structures, earthworks, and other developments where the foundations may be affected;

- the extent to which changes in water will affect connected working or abandoned coal or other mines, e.g. ventilation, flooding at workings, or means of access and egress. In particular, old filled shafts which have in the past remained dry may be affected adversely by rising water levels;

- the natural ventilation to be expected at each shaft and/or passageway intersection through the length of shaft if the main ventilation circuit is interrupted;

- the loading which may be imposed on the cover of filling of the entrance by later developments. In the case of adits, loads within a slope angle of about 45° should be condsidered until the depth of cover is considered adequate.

DESIGN OF TREATMENT

General

When as much information as practicable has been collected and assessments made as indicated above, the various ways in which the objectives of treatment may be met can be considered.

The alternative treatments available are discussed in the following sections and technical considerations are given in Appendix A. Shaft plugs, passageway barriers and dams are practicable only where there is still safe access.

The main factors influencing the choice of treatment are:

- the objectives of treatment as set out on page 1-1;

- location of the shaft and the intended post-reclamation land use;

- access into the shaft;

- gas and water conditions;

- structural conditions of the lining and the nature of the strata;

- future mine workings, including surface mining or other quarrying;

- risks to life and property, including not only the general risks at the surface, but also those which could affect personnel engaged in the operations.

Guidance on the importance of the different factors is given in the appropriate parts of this technical note.

Random Filling

In the past filling of old shafts has been carried out with any material conveniently at hand, including mining equipment and old shaft lining with the sole object of leveling the surface. This form of treatment has proven to be unacceptable and should not be considered as a treatment alternative. However, consideration should be given to the likely possibility that existing fill may be random fill.

It is never certain whether cages, ropes, pipes, and other shaft equipment have been removed, left, wedged in position, or cut loose to drop in the shaft. To avoid the expense of filling the whole shaft, it was not uncommon to install platforms of timber or metal or even makeshifts, at anything from a few, up to say, 30 m (100 ft.) below ground level on which filling could be dumped. On the other hand, fills may extend to a landing at some intermediate level, below which there is a void, or to the pit bottom itself; and there may be nothing but frictional forces on the walls to prevent the material flowing out into the intersecting passageways should the equilibrium be disturbed.

Waste materials which would now be unacceptable as fill material because of excessive compressibility, decay, or toxicity, may have been dumped into some old shafts.

Types of Treatment

The principal features of acceptable treatment used separately or in combination to meet the objectives can be grouped as follows:

- enclosures
- designed filling
- covers and caps at or near ground level
- plugs constructed at depth in the shaft
- passageway barriers and dams

Enclosure.--Well maintained enclosures normally prevent accidental access to an open shaft or adit.

Enclosures should encompass sufficient area to allow for any subsequent operations required at the entrance--in any case access to and around any entrance should be reserved to authorized persons. Two or more shafts may be conveniently included within one enclosure. At adits, the enclosure should extend along the line of the mine excavation to a point where the rock cover is sufficient to ensure protection.

Fences or walls constructed outside the possible collapse area will also protect the area if subsequent subsidence occurs.

The ability of children and others to climb or penetrate walls and fences, using force if necessary, is well-known. This and normal deterioration make continuing inspection and maintenance necessary. Enclosures alone are not likely to provide complete security at open shafts and adits which should, therefore, also have some form of cover.

An open shaft, for pumping or other use, enclosed within a structure specially built or modified for the purpose may be sufficiently secure without a cover if the shaft is fenced to protect operating or maintenance personnel.

Safety fencing and walling to be provided should be determined by circumstances at each location.

Designed filling.--As the deficiencies of random filling become apparent, more care was taken and, in recent years, most shafts have been filled giving due consideration to the surface usage, the shaft conditions, the presence of any equipment or furnishings, and most importantly, to the availability of surface and internal access.

With shaft access it is possible to assess its construction history and condition, determine water entrances, construct passageway barriers, and dams, and remove wall lining in order to improve the efficiency of shaft plugs. Shaft furnishings and other obstructions can be removed as necessary, and concrete can be placed under close supervision.

Internal access into most abandoned shafts for treatment operations is not normally advisable because of the hazard to personnel. Without access, knowledge is limited to records and such information as can be gleaned from the surface, though this may be extended and supplemented by inspections made with television cameras. As any treatment must normally be carried out from the surface, it is generally not possible to ascertain the effectiveness of the measures taken.

Designed fillings in shafts without internal access should begin with removing undesirable material to the extent practicable. Rockfill is then placed in the shaft until it has formed a base reaching to a point at least 5 diameters above the bottom, allowance being made for subsequent consolidation. The rockfill is then followed by general filling, but with further rockfill at any mid-shaft insets and length of impervious soil to prevent the easy passage of water or gas. In some circumstances, it may be appropriate to use rockfill throughout the entire shaft. On a few occasions, dry rockfill has been scaled using cement grout.

Working records should be available for the treatments carried out in recent years. Most designed fillings have been successful; however it is possible that there may be subsidence when the underground workings have not been sealed off, or voids have formed in the fill material. The consequences of possible failures is limited when the shaft is sealed with a strong cap.

Cover and caps at or near ground level.--Covers, used in conjunction with enclosures, are constructed at ground surface over open shafts to prevent accidental entry and illegal dumping. They do not provide protection for the surface against cratering and will not support heavy loads. They may be constructed of reinforced concrete or steel plates supported on beams. The cover should stand above the level of the surrounding ground so as to be clearly visible, permit drainage, and prevent accidental loading.

The cover and fittings, e.g. access holes, vent pipes, pump fittings, should be reasonably vandal-proof; and means should be provided to prevent burrow to the shaft wall.

Adits should be similarly protected by walling up the entrance and securing the roof against burrowing down from the surface.

Caps are reinforced concrete shaft seals constructed from the surface and support on solid bedrock. In the event of the complete loss of filling and collapse of the shaft walling, the cap should prevent subsidence of the surface.

They should be capable of positively and premanently sustaining all ordinary superimposed loads, including the weight of a waterlogged fill material to the surface and may incorporate measures to prevent the seepage of gas. Suction and rebound forces from loss of fill material below should be considered in the design.

Access may be provided through a cap or cover. This should be covered with a reinforced concrete lid too heavy to be removed manually. If gas could be a problem for a period of time, a ventilation pipe fitted with a flame arrestor should be included. A surface enclosure will be required until the issue of gas ceases and the pipe can be sealed.

Plugs constructed at depth in the shaft

General.--Exact analysis of plug behavior is complex, involving the elasticity and permeability of both strata and concrete; and guidance is given in this section for the most practical cases encountered.

Plug Design.--Plugs are constructed by working from within the shafts at suitable points. Because of their shape and thickness of concrete, they can be designed to support almost any loading. The thickness of the plug should in no case be less than the diameter of the shaft.

Plugs should be used when a shaft is to be left open below a stipulated level and the upper section filled or retained for a purpose such as water supply. Such plugs are normally required to be watertight. The construction of plugs is normally only possible in readily accessible shafts. Supplementary measures may be required to insure the stability of the shaft up to the surface before construction of the plug commences.

Only a single downward loading case need be considered, e.g. the weight of a liquified, waterlogged filling, for the full length of the surface and on the external diameter of the lining. A factor of safety not less than 1.25 should be taken with this condition; thereby, providing a factor of safety of about 2.5 when the filling is not liquified, and the weight of most of the fill material is transferred to the shaft walls by friction. The latter will be the normal condition.

It is necessary to check the plug against uplift pressures if there is a possibility of water accumulating in the mine below the plug.

The strength of the plug and strata must be such that the plug will not overload the foundation strata nor fail by "punching" shear in concrete or rock. The permeability shall be such that water will not seep through the plug, along the plug/rock interface, or around through the immediately adjoining strata. Pressure grouting to seal the plug/rock contact and the surrounding strata should be carried out to ensure the required minimum length of seepage path.

When it is permissible for water accumulating in the upper shaft to drain through pipes in the plug to the lower shaft and workings, a filter should be provided on the pressure side to prevent fines clogging the pipes. The possibility of iron minerals or other chemical deposits sealing the filter material and pipes should be considered.

There are two main types of plugs in the shaft. One assumes that the load is carried by the rock strata in direct compression. The earth is excavated to form a large opening, creating a ledge to serve as a load bearing base for the plug. The other type transmits its load to the strata in shear and requires little excavation beyond the removal of the lining and any loose rock. In practice, if the ordinarily permissible shear stresses are used, the radial expansion of the plug which will accompany the shortening in length under vertical loading will increase the factor of safety.

The shape of both types may require slight modification to suit dipping strata.

Concrete should be made with sulphate resisting cement (Type II or V). Concrete made by grouting pre-packed aggregates is often a convenient method of construction in view of the grouting of the concrete/rock interface which is normally required. Reinforcement of the plug is not normally required, but it may be desirable in certain critical cases.

If it is not practicable to remove an existing lining, a plug may be formed within the shaft (wall) diameter provided the lining can be ascertained to be of sufficient strength, the permissible design shear stresses are appropriately reduced, and the concrete and rock interfaces are carefully grouted. The lining requires careful cleaning and preparation.

Plug location.--Several sites in the length of a shaft may be suitable and the final choice depends on strata, requirements in connection with water, construction access, and convenience. Normally, a location as near to the surface as possible is selected. If it is possible to reach this position with standard construction equipment operating from the surface, the plug comes within the description of cap as on page 2-5.

Lower positions will be necessary where shafts are to remain open as sumps for pumping purposes or the loss of water from aquifers is to be prevented.

The strata must be capable of accepting the bearing or shearing loads and after grouting, provide the necessary resistance to seepage. The strata chosen should preferably consist of reasonable thick, homogeneous beds, not steeply dipping or faulted, and without undue fracturing and jointing. Strata composed of a strong bed lying between impermeable beds, if capable of accepting the loading, reduces the amount of grouting required to form a water seal.

Any major fracture zone, created by mining subsidence, at the edge of the shaft may have to be considered. The nearer the plug position is to the surface, the nearer the fracture zone may be to the shaft.

If the desired site is below watertight shaft lining, whether of metal or concrete supplemented by grout injection, a sufficient distance must be left to avoid all risk of disturbing the lining and any seal into the strata at the bottom.

Passageway barriers and dams

General.--To prevent the flow of shaft fill materials into the workings when no shaft plug is provided, mine passage barriers or dams are required. Barriers are provided to retain solids but should permit the flow of water. To prevent water flowing into underground workings, dams will be necessary. Construction of barriers and dams require ready access to the construction location.

The general principles for the locating, loading, and design of shaft plugs should be followed in the design of passage barriers and dams, though the pressures will be horizontal.

Consideration should be given to the structural strength and, if required, the permeability of in-situ rock subject to horizontal pressures from filling. Consideration should take into account any existing voids behind the rock capable of accepting a relatively large quantity of material, should the rock fail. The in-situ rock may be subject to vertical loading from the ground, and the ordinary structural and seepage considerations relevant to plugs are applicable.

Barriers.--Barriers should be as near the shaft as practicable to minimize a void remaining when fill material is placed. Barriers built in a passage adjacent to a shaft are to be designed to prevent any movement of shaft fill material into that passage with consequent collapse of the fill material in the shaft. Movement may be initiated by the action of water on the fill; and therefore, a barrier of coarse rock is often sufficient to preserve stability. The distance from shaft to face of barrier need not normally exceed the passageway height.

The barrier may be constructed of: Rockfill--possibly using rock from the mine; other permanent materials, e.g. concrete blocks or bricks; or a caving of passageway roof and sides.

Pipes situated along the top of the barrier should be included to ensure the passage of water. If there is no provision in the shaft, these pipes may also serve for temporary ventilation. Because the material cannot be packed tight against walls and roof, the minimum thickness of the fill section of the barrier should be not less than three times the greater dimension of the passage.

Rising water levels or cave-in from the roof, which may develop in time, are not likely to have any significant effects on the barriers. Should migrating fines seal the drainage paths through the barriers, it in effect becomes a dam, and unless the thickness is adequate, the consequent water pressures may cause failure.

Care should be taken to pack any adjoining passages or other voids against which there is only a thin barrier of rock.

Dams.--Dams are impermeabile barriers and require the same consideration as plugs with regard to loading, seepage, and structural resistance to pressure. The permeability of the rock in the mine area is likely to be greater than at plug sites in shafts, and large quantities of grout may be required in the grout injection. It may, therefore, be preferable to construct a barrier near the shaft to prevent loss of fill material and construct dams at suitable points where the strata is less permeable.

It is more difficult to prevent seepage, particularly at the rock/dam interface than it is to provide adequate structural strength. In cases where access will still be possible to the dry side of the dam, provision for pressure release and measurements at the remote face should be provided by means of a pipe through the dam fitted with a pressure gauge and valve.

Chapter 3 - OPERATIONS

TREATMENT OPERATIONS FOR SHAFTS WITH LIMITED INTERNAL ACCESS

General

After selecting the most appropriate method of treatment for the particular circumstances of the shaft, it is necessary to complete the design along with drawings, construction and material specifications, inspection and monitoring requirements, and safety precautions.

Construction of treatment measures should be carried out expeditiously as practicable until completed. However, too high a rate of filling can result in air being trapped and consequently increase the amount of future consolidation.

Working on Unstable Ground at the Surface

Before any operations begin, the stability of the ground at the surface should be assessed to ensure the safety of the operations. The nature of any superficial deposits, water levels, and depths to bedrock should be ascertained; and the possibility of the existence of shallow seam workings or voids, such as ventilation drifts, should be considered.

The condition of the lining down to bedrock is important to the stability of the surface, especially if supporting weak or wet ground. Where there is any doubt about the ability of the lining to withstand the thrusts from the ground, including the effects of any additional loading from the operations, a potential collapse zone should be determined and clearly marked with fencing and warning notices.

No person should enter the collapse zone unless wearing safety harness on a line anchored at least 5 m (15 ft.) outside the zone. The line can be arranged to run overhead, connecting several harnesses. Equipment should be similarly anchored to prepared points at least 10 m outside the zone and additional precautions may be necessary for mobile equipment. Steel posts concreted into boreholes form useful anchorages.

In an open shaft, a judgement of the condition of the lining from ground level may be possible with the assistance of approved lighting or closed circuit television.

Treatment of Abandoned Shaft Fillings through Boreholes

Abandoned filled shafts may require drilling to determine their depths and condition of the fill, and the drilled hole can be used to consolidate fill containing voids.

The full area of the shaft top should be exposed and the rig set on girders spanning between beams placed clear of the excavation. The first hole should be drilled at the center of the shaft.

Because unconsolidated and voided fills which cause the drilling water to be lost are often found, it is common practice to drill the casing down first and extract the material within it. Metal and other obstructions frequently necessitate re-drilling.

Methane, carbon dioxide, nitrogen, or mixtures thereof in high concentrations may be present in fill voids, especially near intersections levels; and stringent precautions should be taken against the gas coming to the surface and initiating fire or explosion (See page 6-1). If there are soft deposits overlying the bedrock, consideration should be given to the immediate grouting of the upper length of filling to reduce the possibilities of a surface collapse during operations.

Internal Inspections of Abandoned Shafts

When it is imperative to make an internal shaft inspection of an old shaft, it should be carried out by persons specially experienced in working both in shafts and in support on the surface. Before the inspection, all available information should be studied; and if the shaft is covered, the effects of removing the cover should be assessed.

The inspection should be made from a small sinking type hoist by two men equipped with adequate lights and a signaling bell. By means of a radio telephone, they should keep in simultaneous communication on the same frequency with the hoist operators and supervisor. Before men enter the shaft, the hoist bucket, weighted to the equivalent of the men and equipment and carrying a light, should be given a trial run down to a point as far as can be seen from the surface.

Constant careful checking and assessment of the conditions is required; and the men should not proceed beyond any point without being satisfied with their equipment and the general safety of the environment above them, particularly the stability of the lining and any fittings.

To provide for emergencies, the team should have a plan of action to cover loss of communications. Power should also be available from two sources. Forced ventilation may be required at any time, and a suitable fan and ducting should be on site. A second hoist and fan should be within immediate call. In some circumstances, breathing apparatus may be required for the descent; but such operation of such equipment is outside the scope of this document.

Filling Operations

Abandoned shafts.--Whatever shaft filling arrangement is adopted, there should be at all times, a high degree of stability on the surface to prevent accidental entry. Suitably anchored safety harness should always be worn near a shaft.

Where the stability of the ground near the shaft is doubtful, it is advisable to use a slow speed chain conveyor supported on continuous underframing to minimize vibration ground loading and shock during filling. Such conveyors also ensure an even flow of material. Conveyors may be loaded, via a hopper or directly by earthmoving equipment, at a point at least 10 m outside the collapse zone. Alternatively, cranes with long jibs can work in safety at points outside the collapse zone; but the filling is intermittent, slower, and generally more expensive.

Where the stability of the surface is assured, the filling can be done by trucks or earthmoving equipment. Damage to the lining should be avoided by placing the material in the center of the shaft. The shaft may already have been constructed with a cover through which a centrally located access hole has been provided. If the shaft is open, a platform over a segment of the shaft may be constructed usually at a slope of about 45° to assure proper placement of fill material in the center of the shaft.

Whichever method is used, there must be no possibility of the vehicle or plant overloading the ground, cover, or shaft walls. Stop beams suitable for the vehicles in use should be provided to prevent the possibility of any vehicle accidently entering the shaft.

An inspector should be present at all times to: inspect the material brought for filling; supervise and record the filling operations, including the quantities and types of material; and prevent unauthorized access. A shaft being filled presents a unique opportunity for the unathorized disposal of waste and other objects, possibly even connected with criminal activities. An assistant is required if the materials are to be stock piled first and then re-handled into the shaft. A watchman should be employed to prevent unauthorized access if filling operations are not continuous and entry to the shaft cannot be made absolutely secure.

Water During filling.--If the pit bottom is sealed, or becomes watertight, water entering the shaft will partly remain in the fill and partly drain away according to permeability. Any surplus will rise over the top of the fill material. In settling through water, the fill material segregates with the large-heavier particles settling faster than the small light weight particles. Rock fill should always be used for filling below water level, in shafts where intersection levels are not accurately known.

Provisions for diverting surface runoff away from the shaft entrance should be made at the beginning of the work.

Water entering the shaft will include normal seepage, specifically in-flow coming from the active mining and watertight lining or pipe connections broken by the filling operations.

Water rising on top of fill material is likely to be lost as the level reaches intermediate intersections and the possible effects of this should be considered.

In the final length to the surface, the water is usually absorbed by the ground water table unless the lining is sufficiently impermeable to prevent its escape at a rate compatible with the rate of filling.

If the water comes to the surface, care should be taken to prevent pollution of drains or streams. Acidic mine drainage may deposit ferric hydroxide (yellow boy) after coming into contact with fresh air, and care is necessary to prevent the blockage of pipes connected with shaft and adit drainage.

Generally, it is important to take necessary precautions before interfering with the drainage from abandoned shafts and adits as the compositon and quality of the water may be changed with possible adverse effects.

Measurements During Filling

Measurements should be taken of the levels of the fill material and any standing water, together with the quantities of material used compared to those estimated (See page 3-8).

Records of Operation

Records should be made as the work proceeds as detailed on page 3-9.

TREATMENT OPERATIONS FOR SHAFTS WITH READY INTERNAL ACCESS

General

After selecting the most appropriate method of treatment for the particular circumstances of the shaft, it is necessary to complete the designs, drawings, construction and material specifications, inspection and monitoring requirements, and safety precautions to be followed. As methane normally issues for some considerable time after mining operations cease, emphasis is placed on the precautions to be taken against gas emission.

Clearance of Shafts

Where filling is to form part of the treatment, it is desirable to remove all obstructions in the shaft which could cause voids to occur in the fill material. Ideally this calls for the removal of all platforms, canopies, guide ropes or rails, conveyances, pit bottom equipment, pipes, cables, supporting girders, and other fixtures and projections.

Even with full and safe access, the complete clearance of a shaft is a major operation and the removal of all equipment and fixtures is not always practicable.

Hanging ropes, cables, equipment, and lining not securely fixed and likely to be torn away by falling material should be removed. Platform decks should be lifted and all supports removed. Pipes should be removed, grouted or broken occasionally to prevent a clear continuous passage for water or gas. The first 20 m (60 ft.) from the surface should be removed. There should be no obstructions at insets or the pit bottom to prevent fill material from running into the mine passage up to any barrier which may have been constructed.

The shaft lining should be removed for plugs and water or gas seals as described on page 3-7. Also, all pipes, cables, rails, and other equipment passing through the plug zone should be removed.

Gas

General.--This section gives the full precautions which are required at shafts where there is the potential for methane gas. Expert advice should be sought to determine if all the precautions given below are necessary.

A security zone should first be established around the shaft within which smoking, open fires, coal fires, internal combustion engines, electrical apparatus, unless flameproofed and intrinsically safe, and any other possible sources of ignition are prohibited. The security zone may conveniently be made at the collapse zone (page 1-3). Buildings, air locks, or other roofed enclosures should be opened up, demolished if necessary so that the shaft or adit mouth is well ventilated.

It is advantageous if the general site area is cleared or graded, and materials are stacked away from the filling area to present the best conditions for the dispersal of gas.

A gas testing point for sampling and testing equipment should be established at a convenient location outside the security zone. It should be housed and weatherproof but well ventilated and secure and, if required, supplied with electricity. A barometer is an essential part of the equipment.

All gas sampling and testing should be carried out by personnel trained specifically for the treatment operations.

It is to be noted that the highest concentrations and largest accumulations of gas tend to be found before treatment operations commence and after breaks of ½ hour or more during filling operations.

Gas testing procedures.--Meteorological stations can forecast rapid falls in barometric pressure. Arrangements should be made for these warnings to be also given to the officials responsible for treatment sites.

Prior to any work on the site, the surface security zone should be tested by methanometer. Testing should begin at the periphery of the zone and continue inwards till the shaft is reached. On completion of the testing, shaft sampling tube(s) can be positioned and the site testing point set up.

Where continuous sampling and testing of the shaft atmosphere is carried out, routine surface tests are not normally required other than as a check at the commencement of each shift, or if high concentrations are recorded during operations.

In the absence of continuous sampling, periodic hand sampling and testing of the shaft atmosphere and the surface security zone should be carried out at the beginning of each shift and after work breaks in operations exceeding ½ hour.

If an audible alarm is not fitted to a continuous testing system, the recorder should be inspected at half-hour intervals. Tests for gas should be made as the responsible official may determine necessary.

The gas testing equipment should be checked and calibrated and the sampling tubes should be checked daily for damage.

Continuous gas sampling and testing arrangements.--In addition to surface tests, the atmosphere in the top 25 m (75 ft.) of a shaft should be continuously sampled and tested. The usual system is by means of a vacuum pump drawing air continuously through a 6 mm (18 ft.) dia. PVC tube hanging freely in the shaft. The air is then analyzed at the surface. There are also sensor heads capable of analyzing the gas at the sampling point and transmitting the results electrically to the surface, but in practice, it has been found that the leads are easily damaged, so the system is not recommended for use in shafts.

The samples should be obtained from prescribed levels, say near the surface (but below any fan drift or other surface opening) at depths of 20 m (60 ft.), 50 m (150 ft.), and 100 m (300 ft.), including any known intersections within the 100 m (300 ft.). When the backfill reaches 100 m (300 ft.), sampling should continue with the tube being raised just ahead of the material.

General practice is to pass the air to a gas analyzer giving a continuous indication of the methane content. A recorder and an audible or visible alarm operating at a pre-determined percentage of methane should be connected to the analyzer. The pump, analyzer, and recorder should be contained in weatherproof well ventilated housing, and electrical equipment should be flameproofed.

A connection in the pump discharge can be provided for taking samples for testing for methane in a handheld methanometer as a check on the analyzer, or for testing for carbon monoxide and carbon dioxide in a multigas detector.

Analyzer readings of methane content assume that the oxygen content is normal, so periodically, complete laboratory analyses of the gas are necessary to check oxygen and nitrogen content and to identify any other gases which may be present, particularly hydrogen sulphide.

An instrument has been developed to provide continuous indication and a record of:

methane - by the use of a pellistor detecting element;
oxygen - by the use of a polarographic cell;
and barometric pressure.

The mine air is drawn through a small bore (3 mm 1/8 inch) shaft tube by a pump and passes it to the detector. An audible alarm can be fitted, and the electrical equipment can be operated either by a 110 volt electrical supply or 12 volt batteries, which should be flameproofed if used within the security zone.

It is essential when sampling to ensure that gases from extraneous sources, such as internal combustion engines are excluded.

Permissible gas concentrations for operations.--The concentrations of particular mine gases at which treatment operations from the surface may begin, continue or are discontinued, depend on local topography, whether or not the work area is built up or open, barometric changes, the predominant gas, and the quantities emitted. The permissible limits when working below ground must meet the requirements of mine safety regulations.

Gas testing records.--Barometric readings, air flow observations, and the result of all gas sampling and testing should be systematically recorded and kept available at the site while workmen are there.

Construction of Plugs

When a suitable site has been chosen, and a section of lining is to be removed, a working platform is established which must be strong enough to bear the weight of the wet concrete plug until it is self supporting. Pipes for water or ventilation can be incorporated and should extend above the top of the plug as necessary. The bottom ends of the pipes should have a plate or other device to retain concrete if they are to be sealed later. The deck of the platform is the bottom form for the plug concrete but access through the platform may be temporarily necessary to comply with the requirements of mine safety standards.

Debris from the lining and excavation can normally be dropped through a suitably guarded hole in the platform into the shaft below. This may not be permissible because of gas or other reason; and if there is no other convenient void, the debris must be lifted out of the shaft.

Reinforcement may be assembled in sections at the surface for convenience in lowering and fixing into position. Care should be taken at the bottom of the plug that the reinforcement is fully encased in the concrete. The normal concrete cover is at least 150 mm (6 in.).

Pipes are required specifically for injecting grout into the plug/rock interface zone and will also be required if the plug is formed with pre-placed aggregate, which is to be injected throughout with cement grout. This is often a better and more convenient form of construction primarily as shrinkage on setting is negligible, so reducing the risk of rock/plug interface seepage.

Before placing concrete, the excavation should be cleaned and shaped to ensure that air and water will not be trapped, relief pipes being included if necessary and loose rock and dust removed.

Ventilation systems will be required at any time there are people working in the shaft.

Impervious Soil Seals for Water and Gas

After a section of lining is removed from the level selected for the seal, the strata should be examined at sufficient points to ascertain that it will meet the permeability requirements for the imposed head of water. The lining above the seal must be left adequately supported or removed. The raw edges of the broken lining should be shaped or secured, so that it is not likely to be broken during the filling operations.

The soil selected for the seal should be reasonably broken up and brought to a plastic consistancy by the addition of water before or during the filling.
The material should be introduced when the highest point of the ordinary fill is one or two meters below the exposed strata and continue for the length of seal required plus the allowance for settlement.

Filling of Shafts

The filling of accessible shafts is carried out in much the same manner as for unaccessible shafts .(See page 3-2). Where the surface ground conditions are weak, the procedures outlined on page 3-1 shall be followed.

Filling of Adits

The barrier or dam required to prevent the loss of material down the adit or to prevent entry of humans and animals should be designed and constructed on the principles described (See page 3-7). The site should be at a sufficient distance in from the surface opening, considering the over-lying strata, where there is little danger of collapse. A distance of at least 5 times the passage-way height is considered minimum. Where permeable barriers are used, it may be necessary to consider the provision of a separate specially designed gas seal. The filling material may be taken in by conveyor, mine car, or slurried with water and placed with a pneumaticly operated machine. If adequate ventilation is available, small earthmoving machines may be used. Fill materials can also be placed in adit be sealed on completion of the work with fine concrete or bentonite clay plugs to prevent the passage of water. The fill material can be grouted from within the adit itself or through surface boreholes.

The work should be completed by regarding and protecting the surface area in a manner appropriate to the proposed future land use. There should be 1 m (3 ft.) minimum depth of soil material over the remains of the walls, floor, etc.

Where adits are producing, or are likely to produce water, provision for drainage must be made taking precaution against unauthorized entry and the possible emission of gas. It is important to carefully study any interference with the drainage from old mines as the established drainage systems may be adversely affected.

Filling Old Shafts in a Complex

The filling of old shafts adjacent to working shafts is normally to be avoided. If, however, there are unusual circumstances and such a shaft is to be filled, dams should be constructed in all the connections to the adjacent shafts and workings, special attention being paid to in-situ rock barriers between the shaft and adjacent workings to insure adequate thickness for strength and permeability.

During the operations, it may be necessary to reduce shock loading from falling materials to prevent disturbance of the structure and operations of any of the adjacent shafts. In extreme circumstances, it may be necessary to hoist the fill material into the shaft.

Measurements During Filling

Soundings.--During filling, it is necessary to physically check the level of the material and any standing water. It is normally adequate to take single soundings at a point on the periphery of the shaft. When critical levels are being approached, point soundings should be averaged.

Soundings should generally be at close intervals of time when required to ascertain levels given in the specification for critical positions, such as for change of types of fill or to complete to a given level. Throughout the shaft filling soundings should be made at the beginning and end of each shaft.

Quantities of filling material.--The workmen should record the amount of fill placed as accurately as practicable, e.g. by bucket or truck-size load, or preferably, by weight. The quantities used should be checked at least daily against the estimates of the quantities required.

Should a sounding indicate a fill level greatly different from the level calculated from the quantity of filling material used, work should cease until the situation can be assessed and necessary action taken.

Records of Operations

Accurate and detailed data on all shaft treatment should be recorded throughout the treatment operation. All positions, dimensions, materials used, standards of workmanship reached, equipment, or obstructions left in place, type and condition of strata, quantities of grout and pressures achieved, makes and loss of filling, unusual occurrences, and other details of the construction work should be recorded and the plans and specifications confirmed or noted as appropriate.

Photographs, if available, can supplement the written records and all features such as plugs, barriers and dams should be recorded.

APPLICATION OF SAFETY & HEALTH STANDARDS

The safety and health standards established for mine operations by the U.S. Department of Labor, Mining Enforcement, Safety and Health Administration, should be used as a guide for shaft and adit treatment. A superintendent and inspector must be on the job at all times to insure compliance with safety and health procedures.

SUMMARY

The ultimate aim of any work carried out at the site of an old shaft or adit is to ensure that the surface at that point is made stable, and to this end this technical note describes the various treatments which may be carried out. The final choice; however, must be made according to the circumstances, including location, results of investigations, and future use of the site in each individual case.

It is not normally advisable to rely permanently on an enclosure as a means of ensuring security. Frequent inspections and maintenance are necessary until permanent treatment is installed.

The most expedient permanent precaution for abandoned shafts is the construction of a cover over the top of the shaft combined with filling operations. This insures reasonable protection at ground level even though the shaft fill may settle or even be lost in the long term. Stability of the fill may be obtained by grouting or by barriers and/or dams erected at all shaft and passageway intersections. The latter are expensive and are only justifiable if the insets connect directly to other underground workings which are still operational.

Any temporary arrangements introduced for ventilation or dealing with gas emission should be finally sealed off as soon as possible after cessation of the operations. Any enclosure should be retained until such time as this has been done.

Suitably inscribed permanent markers can be used on the sites of shafts which have been treated so as to indicate their presence.

TECHNICAL CONSIDERATIONS
STRATA CHARACTERISTICS A-1

Geology and Hydrogeology

A study of the geology and hydrogeology should reveal the significant features of shaft stability and the success of any treatment, particularly the engineering characteristics of the soil and rock around the shaft and the quantity, pressure and quality of water within them. Account must be taken of the effects of past and future mining subsidence, the changes in the movement of minewaters arising from mining operations, and the possibility of treatments causing pollution of the strata.

The study should include an examination of the available installations records - these normally give the levels and characteristics of water as well as the strata encountered.

A section of the shaft or adit showing all relevant information should be prepared for inclusion in a treatment specification.

Superficial deposits.--Except for man-made fills and organic materials, superficial deposits are either derived from weathering of the local rock, or may be material transported and deposited by natural processes.

Superficial deposits being uncemented are much weaker than most rock formations and may contain water that affect their behavior.

The effects of weathering on superficial deposits should be considered. For instance, drainage of a cohesive material may lead to its consolidation and the possible formation of shrinkage cracks and fissures.

Solid rock.--These vary widely in mineralogical and chemical composition and in hardness and physical strength. The arenaceous sedimentary rocks range in texture from loose sands and gravels to compact, massive sandstones and conglomerates, while the argillaceous sedimentary rocks range from soft, plastic clays to hard, fissile shales. The other principal group of sedimentary rocks, the limestones, also vary within wide limits of hardness and strength. Other rocks such as ironstones or igneous and metamorphic types, which are occasionally encountered in shafts and adits in coalfields, are generally intrinsically hard.

The stability of excavations in rock is dependent to a considerable degree upon fractures resulting from tectonic forces or from mining activities. These fractures include faults along which movement has occurred and joints which have been produced by negligible movement. The orientation, inclination, frequency, and tightness of the various types of fracture influence the behavior of the strata.

Mining operations may cause the strata to subside and this is accompanied by compression or extension. In the tensile zones, the strains generally concentrate at joints or other planes of weakness.

Mining subsidence movements and weathering may in time affect the rock behind shaft or adit linings reducing its competence.

Aquifers.--Aquifers are strata containing appreciable quantities of water and permitting its easy movement, e.g. sands, gravels, sandstones, limestones, and some igneous rocks. Water flows more easily through open fissures, but in some coarse rock types appreciable flow may occur through the pores.

The effect of mining subsidence is to increase or reduce permeability depending on whether the rock has been subjected to tension or compression, but rock once fractured due to tension normally maintains a higher level of permeability even if compressed again later. Fractures and open joints can create permeability in rock otherwise impermeable.

The effects of faulting on the hydrogeology often cannot be predicted. In some cases, a fault zone may be permeable and enlarge the drainage area feeding an aquifer. Conversely the zone may be impermeable.

Levels and movement of water.--In an unconfined aquifer, the water-table is at atmospheric pressure, and its level may be determined in boreholes. The water-table varies in profile and depth below the surface according to season, drainage and differences in strata permeability.

In a confined aquifer the water is usually under pressure, such that when encountered in a borehole, it will rise to a level above the upper surface of the aquifer. If the final level is above the confining strata, an artesian condition exists.

The movement of water in the ground follows the principles of hydraulics, and it should be noted that the main migration path of water through the aquifer is not necessarily in the same direction as the dip of the strata.

Water is a significant factor in the deterioration of shaft linings and in their stability. For example, water flowing behind the lining and eroding the back-filling or strata may leave the lining as a free standing wall liable to collapse under horizontal pressures.

Quality of water and its significance.--Research on mine-waters has made it possible, in many cases, to assess by chemical analysis and correlation, the source of any particular water, the strata through which it has travelled, and whether there has been contact with mine workings. The research is of particular value in revealing the existence of possible water hazards from old mine workings.

The manner in which water quality varies with depth is now well established. In general, the corrosiveness of the water to structural materials, such as concrete, iron and steel, increases with depth because the number of salt types present and their concentrations increase. Acidic waters also attack concrete, limestones, iron and steel. Calcareous material that often cement rocks together is particularly subject to attack and solution by acidic water.

Potential for contamination of aquifers.--Contamination of an aquifer may occur from the surface through the shaft itself, or by seepage through cavities behind the lining, or from underground sources in mine workings. Such contamination is a particularly important consideration, if the aquifer is a source of potable water, special protective measures may be required.

Mine Gases

Accumulations of methane, carbon dioxide, or nitrogen with a defiency of oxygen are to be found in most coal mines. Carbon monoxide, and in rare cases, hydrogen sulfide may also be found. Other gases may occur if domestic refuse has been dumped in the shaft. Mine gases may not always be present but concentrate rapidly as barometric pressures fall.

Natural air flow depends on barometric pressure, depth, variation of temperature, and humidity. Changes taking place in the mine, such as rising water levels or collapsing workings, may result in gases appearing at the surface. Complete reversals of air flow may occur suddenly, especially during filling operations. The gas may migrate to and accumulate in shafts, adits and areas on the surface adjacent to the opening.

The filling of shafts reduces the possibility of large accumulations of gas, but it should be remembered that most fill materials consolidate; thus, creating cavities at the surface and elsewhere in the shaft length.

Carbon dioxide and nitrogen (oxygen deficiency) are most likely to be found at the bottom of all shafts and adits. Gas pressure may build up against covers and plugs resulting in gas emerging at the surface particularly as atmospheric pressure falls during barometric changes, or as water levels underground rise. The principal risk associated with carbon dioxide and nitrogen is asphyxiation in unventilated places and can extend to low areas on the surface, if the air is still.

Methane is present in most mines, and in "gassy" mines significant volumes continue to be emitted from the strata for some time after working ceases. Eventually, however, the accumulation dwindles and methane is not often found at the entrances of long abandoned mines.

The main hazards from gas are:

- ignition and explosion of methane may be caused by open flames, e.g. open fires, smoking, welding equipment, fireworks;

- sparking from electrical apparatus;

- sparking from friction of metal or rock containing quartz or pyrites on metal furnishings during treatment operations;

- hot or burning material at the mine surface or used in filling;

- asphyxiation in oxygen deficient atmospheres;

- poisioning by carbon monoxide.

Mine gases which may exist before, during, or after shaft treatments have an important influence in determining the nature of the treatments and the operational methods adopted.

At a sealed entrance, it may be necessary to provide ventilation pipes, fitted with flame arresters and protected by lightning conductors, to allow gas to escape freely to atmosphere. In the absence of such measures the gas may follow paths provided by cracks, fissures, fan drifts, pipes, ducts, and culverts either to atmoshpere or into parts of nearby surface buildings which may be inadequately ventilated.

FILLING MATERIAL A-2

Principal Materials Available for Treatments

Materials, other than structural steel and brick used in shaft and adit abandonment work, can be classed as general fill; fills for specific purposes and concrete.

General fill.--Such fill material should be capable of flowing into voids and giving support to any lining or to the ground itself. It should not have any unacceptably adverse quality such as toxicity, combustibility or poor mechanical properties which could affect performance during or after filling.

Most granular materials which are basically stable are acceptable, and typical examples are shale, broken stone, mixed brick or concrete demolition, rubble and quarry, and steelworks wastes. Quartzite or other hard rocks can cause sparking during free fall and should be used with caution in conditions where there may be methane gas. For the same reason, steel and iron should be excluded from all fill materials. Aluminium, magnesium, titanium, and their alloys should also be excluded because of the possibility of a thermic reaction.

Fills for specific purposes.--Examples of fills for specific purposes rock fills, impervious fills, and coal preparation plant tailings.

Rock fill.--The chief use of rock fill is at pit bottoms, and at intermediate levels where it will run into passages and build up at its natural angle of repose. A sufficient length of rockfill in the shaft may be used to support weaker, softer fill material. Being free draining, it will also enable any water to pass out into the workings, provided the drainage paths do not become blocked with migrating fines.

Rock fill includes all clean, hard, and durable material of maximum size not normally exceeding about 250 mm (10 inch) cube. Exceptionally, a maximum length of 500 mm (20 inches) may be permitted, but such oversize material can easily damage shaft lining. It should be inert, insoluble, and resistant to groundwater attack. The grading should be such as to give a reasonable density of filling and provide an adequate filter drain.

A suitable grading is:

250 mm (10 in.) - 20 mm (0.8 in.) - up to 80%
20 mm (0.8 in.) - 2 mm (0.08 in.) - up to 15%
less than 1 mm (0.04 in.) - not more than 5%.

The height of the rock fill above an inset should be not less than five times the shaft diameter plus an allowance for the expected compression of any material below. This allowance can be taken as 10% less the amount of compression observed when soundings have been taken during filling.

Consideration should be given as to whether waterlogged fine material placed on rock fill will migrate into its pores because the presence of the fine material will impair its drainage properties. In doubtful cases, the rock fill height of five diameters above the inset should be increased.

Impervious soil.--This refers to materials having a coefficient of permeability less than 1 x 10^{-6} cm/sec (.0014 in./hr.), which are used to restrict the movement of water or gas within the shaft, or the entry of water from the surface. Satisfactory material can sometimes be found close to the site, but if the material is dry it will require thorough working and wetting until sufficiently plastic to consolidate into an effective seal. Bentonite, an expansive montmorillonitic clay, or pulverised fly ash, may be used as an additive to obtain plasticity in sealing materials.

Soil seals are best compacted into position. However, this is rarely practicable in shaft work, and it is necessary to rely on great thicknesses of relatively plastic material to effect a seal. Seal material is slow to consolidate and the settlement, which may be considerable, will occur over a long period.

Pulverised fly ash is often used in conjunction with cement or bentonite to grout voids within fills. Used alone, its susceptibility to liquefaction makes it unsuitable for general filling.

The addition of between 5% to 10% of cement to pulverized fly ash produces a material which sets up in a similar way to concrete, though, with somewhat lower strength. It has the advantages that it can be pumped considerable distances and may be dropped through an appreciable height without segregation and has a low bulk density.

Coal preparation plant tailings.--Froth flotation tailings cakes from coal preparation plant pressure filters may be sufficiently impermeable for use in seals. The cakes should be plastic so as to compact and consolidate into a solid mass under their own weight and that of any filling above. As with clay, a considerable amount of consolidation may occur over quite a long period.

At shafts or adits suitable for the disposal of liquid tailings and slurries, it is usually intended that the material will enter all the underground mine openings into the shaft so that as much as possible will be accommodated. After a series of build-ups and collapses, the tailings eventually fill the shaft; but such fillings are totally insecure and permanent measures such as covers or plugs are required.

<u>Concrete</u>.--Concrete may be used either as good quality mass fill or for structural purposes. The mixing, placing, compaction, and curing should be controlled generally as required in quality concrete placement; but some requirements may be very difficult to achieve in the conditions under which shaft works are carried out. Allowance should be made for the possible deterioration in strength and chemical attack by aggressive water. The best defense against chemical attack is good quality concrete coupled with density and thickness of structure. Deterioration is much slower when there is no movement of water.

Placing of concrete in "dry" shafts.--The placing of concrete in shafts is never easy, and the methods which may be adopted usually result in lower strengths than those achievable in surface work.

Batch mixing outside the shaft with controlled placing is the more usual method. Good results can be assured, but it is slow, expensive, and workers are required in the work area.

If fresh concrete is dropped freely over 5 feet, the constituents segregate and produce a non-homogenous mix showing wide variations in strength and having considerable porosity. Some zones may be completely devoid of cement.

Concrete dropped through a drop chute or a pipeline and discharging from an unrestricted open end is similarly liable to segregation.

Where workers are not able to be present to observe the placing, any reinforcement or pipes to be incorporated in the work may be damaged or displaced.

Where workers can work at the point of placement, steel containers fitted to the end of the shaft pipe overcome the problems of segregation. The container reduces the momentum of the concrete and brings about some remixing of the material, which then overflows through the flexible pipes to the placing points.

With correct mix design the risk of pipe blockages is not great. However, care must be taken that water over and above that required for the mix is not mistakenly added to prevent blockage. The pipeline must be plumb if gravity flow is used and securely fixed in position as considerable vibration occurs in use. The pipe should be coated with grout before and cleaned out with water and gravel after use. It is important that the concrete mix should not be varied without the authority of the designer. Where possible, the whole operation should be carried out in one continuous lift to obviate the possibility of joints being formed or dirt lenses included.

A better method, however, is to place good quality concrete into bags which are then dropped down the center of the shaft. In dropping concrete or concreting materials freely in a shaft, a considerable proportion will be lost on the walls and fittings and not reach the desired level. Allowance for the loss must be made.

Placing of concrete into "wet" shafts.--Concrete should not be dropped into water as the cement will strip from the aggregate, and the constituent materials will segregate into layers of cement and fine and coarse aggregates. Underwater placing requires the use of tremies, special skips, or alternatively, methods involving the grouting of in-situ aggregates are used. Highly specialized workers and supervisors are necessary for this operation.

Placing of concrete in adits.--Concrete may be placed in adits more easily. Pumping from the surface is the most appropriate method if justified by the amount required; otherwise, the addition of water to bags of ready mixed cement and aggregates taken to the site of concreting is a convenient method.

Other methods of forming or placing concrete.--Aggregate placed in position dry can be grouted solid through pipes incorporated in the work. It is important to provide pipes or openings through which air and water can be expelled. This method often offers considerable advantages and obviates the need to grout the concrete/rock interface zones of plugs and dams as a separate operation, though grouting of the strata is still necessary.

Geotechnical Features of Filling Material

Water.--Water can have a profound effect on the behavior of soils and, therefore, on shaft fillings. It is likely to be present as the natural moisture of the fill material, and additional water may percolate into it through the shaft lining or from the workings.

Unless there is natural gravity drainage from the shaft, the probability in the long term is that water will rise in the shaft to the level of the natural ground watertable, and all fillings should accordingly be considered to be waterlogged.

Water draining down through fill with rockfill at the base can pass provided that fine material does not migrate and seal the drainage paths through the base. Variation in water level can induce the collapse of a general fill material containing voids, thus, causing at least settlement and, at worst, liquefaction of the fill which may then be able to escape by flowing into the old mined out area.

If water has already accumulated in a shaft, it is preferable to use rockfill throughout, or at least until the fill is above water level, in order to avoid segregation in the materials, excess pore pressures, and settlement.

Internal pressures in a fill.--Stresses within shaft fills have not been measured, but the knowledge gained from investigations into the stresses existing in tall silos for holding grain or other granular material is considered comparable.

In a circular silo filled with material at rest, the vertical walls act as a hoop to contain the material and the resulting internal horizontal pressures permit the development of friction between the contents which transfers a portion of the vertical load of the fill to the wall. In practice, below a depth of about three diameters, it is found that the horizontal and vertical pressures within the silo contents increase no further. The vertical pressure remaining represents a height of filling of about three diameters and is the amount of dead weight normally carried directly on the material below or on the silo bottom.

The foregoing applies also to shafts filled with dry materials. When the fill becomes waterlogged conditions change. The angle of friction of the material on the wall is not much affected itself, but the effective weight of the material is reduced by the buoyancy of the water. Hydrostatic pressures must then be added to other horizontal and vertical pressures. Providing the ground surrounding the shaft is stable, the horizontal pressure has little effect; but if the workings and the shaft base remain dry, the base must withstand the weight of fill material amounting to three diameters, and the total weight of the inundatory water.

A strong rockfill should not be expected to support the weight of a waterlogged length of weaker or finer materials. It may collapse and allow the whole fill to flow dramatically.

A complication in the long lengths of shafts is that even slight variations in material properties can produce different behaviors. In particular, the amount of settlement may vary, producing cavities in the filling which may be large. Movements of large volumes of material following the collapse of cavities can result in shock loadings and increases in pressures leading, in some cases, to liquefaction of the whole filling.

Water rising in the workings and up the shaft should have only marginal effects on the material properties, apart from buoyancy effects. Conservative designs should assume a water-logged shaft with no more water in the workings than about coal seam height. In this way, only the buoyant weight of any roadway barriers, dams and cavings is effective in containing the shaft fill.

Settlement.--Provided fill is not flowing into the workings, settlement at the surface of a filling results primarily from consolidation of the material by expulsion of water and air from between the particles, and the collapse of solids into the larger voids occurring in the filling. The compression and reorientation of particles under pressure make a comparatively small contribution to the total settlement.

The amount of settlement is determined by the vertical pressures developed by the depth and density of the material, accounting for water entering or standing in the fill, and the relief afforded by wall friction. The rate of consolidation depends on the rate at which excess pressures created in the water or air confined in the pores or voids can dissipate, which in turn depends on the permeability and lengths of the available drainage paths through the material and in the structure of the shaft and its lining.

As the excess pore pressure dissipates, the vertical stress is transferred from the contained water or air to the soil structure.

A considerable proportion of the total settlement occurs during the filling operations. From experience, depending on the material, the amount of further settlement on completion of filling can be as much as 20% of the total fill length over a period of a few months.

In the case of a long length of a shaft fill, the rate of consolidation cannot be uniform, and cavities will occur in places. The collapse into such cavities may contribute to the situations discussed in this appendix.

Clay Seals for Water and Gas

Clay seals to preclude the possibility of substantial seepage around the clay seal may be effective in preventing the passage of water when placed against impermeable strata, such as shales and mudstones of sufficient thickness. However, it is doubtful whether a comparatively short length of clay is significantly more effective than longer lengths of a general fill which includes more than 20% of material finer than 76 microns (.003 in. or No. 200 sieve).

For water, a minimum thickness of clay of 5 m (15 ft.) placed against impermeable strata is required, together with allowances for settlement of the fill below, and inaccuracies in shaft soundings. Clay seals cannot be considered fully effective unless either the shaft lining has been removed for the full length of the seal or grouting has been carried out to ensure that the water or gas is not able to bypass the seal behind the wall.

Clay has also been used in attempts to prevent the migration of flammable gases, but probably because any fill material is very much more permeable to gas than to water, many of the attempts were unsuccessful. Mining experience shows that gas will seep through any type of soil material used as backfill of shafts, particularly when there is a pressure gradient in favor of migration in the direction of the surface.

The best location of a gas seal is above the highest workings inset but below any ventilation or other insets near the surface. Generally, the highest possible position in the shaft is selected but should be borne in mind that the strata may be disturbed enough to permit the gas to escape to points remote from the shaft unless it is grouted.

Adverse Effects of Shaft Fittings on Fills

Platforms and furnishings.--Shafts have platforms and furnishings which are often difficult to remove even when access is possible. Without access even their existence may be unknown. Such features may affect fills adversely by creating voids and arching, and by providing drainage paths for water and gas.

Platform framings, even without flooring, are capable of causing the formation of complete bridges in the fill as are a number of adjacent, smaller obstructions.

Hanging guides, cables, and pipes may not only cause voids but are tensioned by the drag of the filling. The load is transmitted to the anchorages which, if in the headgear or other point at the surface, may cause serious collapses. Alternatively, should the tensioned members break, the sudden release of strain energy may also have serious repercussions at the anchorages and constitute a danger to personnel.

Guides, cables, and pipes passing through the fill provide a ready path for water. The subsequent erosion of the fill material creates a "pipe" capable of passing large quantities of water or gas. Obstructions also retard the rate of consolidation and settlement.

Lining.--Apart from the projections, usually for furnishings, linings may have been cut through leaving raw edges. Material falling on projections and raw edges can bring down areas of lining large enough to block the shaft. Brick and block linings are often backed with ash or other loose filling which will permit the passgae of water down behind the lining. Linings deteriorate with time and may collapse from weakness or from the pressure of water in the backing, if there is a water level within the shaft lower than that in the strata.

Watertight lining is generally only used for holding back large quantities of water at high pressure. Metal lining, especially the cast iron sections, is usually strong; nevertheless, there is a risk of damage or breakage by heavy or large pieces of falling material. Connections into watertight lining, usually for water supplies to the mine, are susceptible to damage during filling operations. Where there is access in the shaft, such connections should be sealed off whenever possible to prevent the free entry of the water to the shaft fill. It is also advisable to seal off the shaft below the base of the aquifer to prevent, or at least reduce the rate of loss of water into the aquifers and mined out areas below.

The Stability of Files

Rockfill or similar material, placed loosely at intersections and pit bottoms, has been observed on many occasions to stand at its natural angle of repose from the bottom of the shaft into the mine workings under considerable weight or dry fill. This indicates that it was not subject to excessive loading. This is further confirmation that in a deep cylindrical container the main weight of the contents is transferred to the walls by friction. This transfer of load is effective in shafts with a height in excess of about 3 diameters. The wall must then be capable of accepting the weight of the filled materials. At intersections both the lining and the strata supports are likely to be weakest. At these points, there may also be sudden high dynamic forces should there be movement of the fill.

Excess pore pressures, large water flows, and saturation of fillings are key factors in fill stability. Sudden ground shock from seismic activity; mining subsidence due to workings under the shaft, or in the shaft pillar; the yielding of barriers of weak soil; or the collapse of filling into voids, may provide a disturbing force sufficient to bring about liquefaction of the fill material and accompanying high pressures.

Voids in the shaft are also likely to occur as a result of differences in material properties. The fill may, thus, be divided into lengths which can move independently. Many borings through old fills have confirmed the presence of voids.

Sudden loss of filling creates a vacuum which may pull in the lining, especially if it is damaged or deteriorated or there is water or loose ground behind the shaft wall to exert its weight. There may also be rebound effects as the voids fill. Collapse of a lining supporting weak strata will allow the ground to follow and run into an open part of a shaft. Lining failure may permit cratering to occur around the shaft opening when there is weak ground at the surface.

Weak in-situ rock barriers between shaft and a major void, such as a mine passageway, are vulnerable points whose presence in many cases is unknown and cannot be detected.

A long period of fill stability is not evidence that such conditions will continue. Many well designed and executed fills with substantial rockfill bases have remained in position for long periods. They may, however, be unstable and the possibility of sudden collapse cannot be ruled out unless there are effective passageways. The presence of a substantial cap or cover or suitable overfill should prevent the disastrous loss of fill material.

Placing of fill materials too fast can result in a high percentage of voids in the in-situ material which can affect stability in the long term.

The placing of material at a slow rate is acceptable, providing that it is placed sufficiently fast to ensure that the water level in the shaft does not rise at a faster rate than the fill. If this happens segregation will occur, compaction will be low, and voids will form.