Chapter 8.7
MINE CLOSURE, SEALING, AND ABANDONMENT

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8.7.1 INTRODUCTION

All mines will eventually close. When a mine permanently stops operating due to economic conditions, the depletion of reserves, or any other reason, the following activities generally occur:

1. Underground mine openings are sealed.
2. Surface facilities are removed.
3. Surface mines and the surface areas of underground mines are reclaimed.

Only after these activities are completed can the mining company abandon the site. However, even after the mine is abandoned, specific postmining liabilities rest with the mining company. This chapter presents aspects of the closure, sealing, and abandonment activities.

8.7.1.1 Definitions

To enable the reader to interpret this chapter, the following definitions are provided.

Closure: The act of closing or the condition of being closed, such as the closing of a mine. There are different degrees of closure: permanent, temporary, and semi-permanent. In this chapter, it is considered that the closing of a mine is permanent. Mines that are not open for production but that could be reopened should be considered as temporarily or semi-permanently closed.

Sealing: The securing of mine entries, drifts, adits, slopes, shafts, and boreholes with suitable materials to protect against fires, gas, and water emissions and for the safety of the public (Foreman, 1971; Thrush, 1968).

Abandonment: The act of abandoning and relinquishment of a mining claim or intention to mine; a voluntary surrender of the claim or mine to the next party. This differs from forfeiture that can be considered the involuntary surrender of a mine by neglect (Thrush, 1968).

8.7.1.2 Regulatory Requirements

In the United States, federal, state, and local governments have issued regulations that must be followed during the closure of a mine. Because regulations may change, a summary of only the existing federal regulations is presented in this chapter. Federal agencies that regulate mine closure activities are the Mine Safety and Health Administration (MSHA), Environmental Protection Agency (EPA), Office of Surface Mining Reclamation and Enforcement (OSMRE), US Geological Survey (USGS), Bureau of Land Management (BLM), US Forest Service (USFS), National Park Service (NPS), and Bureau of Indian Affairs (BIA) (Anon., 1980a). MSHA regulations are applicable for health and safety standards and apply to all coal and noncoal mines. EPA's water discharge effluent limitations apply also to all coal and noncoal mines. OSMRE reclamation regulations apply only to nonanthracite coal mines. Pennsylvania anthracite mining regulations apply to all anthracite coal mining by OSMRE reference. Since the other agencies (USGS, BLM, USFS, NPS, and BIA) have jurisdiction only in federal lands, their regulations are not presented. If applicable to a specific mine, these agencies should be contacted directly.

A brief synopsis of the applicable federal regulations appears in Tables 8.7.1, 8.7.2, and 8.7.3.

Individual states have different rules and regulations that must be followed during the closure of mines. All states must follow the federal OSMRE regulations as they apply to coal mines. OSMRE regulations allow states to request primacy in self-regulating these rules and regulations. Most states with coal mining activities have passed their own regulations that closely resemble the federal OSMRE regulations, thus regulating their coal mining industry. Individual state health and safety rules may differ from the MSHA rules and must be considered in addition to the MSHA regulations when closing a mine.

Local government may enact rules covering topics such as (1) zoning (which could affect the selected postmining land uses) and (2) land value assessment (for taxation). It is suggested that engineers involved with a mine closure contact their local and state regulatory agencies to determine if any local regulations apply.

8.7.2 MINE CLOSURE PRACTICES

8.7.2.1 Surface Mines

The closure of all new surface mines must be planned prior to the beginning of operation. A reclamation plan must be included with all new permit submittals. This planning is also important in evaluating the economic justification for the mining operation. A substantial amount of money can be saved if the most appropriate reclamation or closure procedures are thoroughly considered and carried out as planned.

Unless an alternative plan is approved at the closure of a surface mine, the mine site must be regraded to approximately the original contours. Backfilling should remain as close as possible to the active mining area, not only to reduce haulage distances but also to save on reclamation costs in the event that the surface mine must be closed and regraded due to economic conditions prior to its planned closure.

Reclamation planning and closure methods vary among types of surface mines. Some different methods are discussed briefly here.

Open Pit Mines: *Open pit mining* is defined as "the mining of ores (primarily referring to metalliferous ores) by surface mining methods where waste or overburden is first removed, and the mineral is broken and loaded" (Thrush, 1968).

At the present time, the closure of open pit mines is controversial. Currently, there are no federal regulations covering the closure of open pit mines. The operators must contact local and state agencies to determine what requirements must be followed at those governmental levels. According to Dohm (Crawford and Hustrulid, 1979), the increased environmental awareness (of open pit mining) definitely indicates that proper production planning and scheduling can minimize the costs associated with mine reclamation. The items most effectively handled by efficient planning are (1) returning ground contours to approximate premine conditions by blending in the new grades with the surrounding topography, (2) minimizing surface depressions to the greatest extent possible, and (3) revegetating all disturbed areas.

Table 8.7.1. Federal Regulations Applicable to Mine Closure, Sealing, and Abandonment, Mine Safety and Health Administration, *Code of Federal Regulations,* Chap. 30

Regulation	Paragraph	Description
Part 57—Metal and Non-Metal Underground Mines—Safety and Health Standards	57.1000	When any mine is closed, the person in charge shall notify the nearest subdistrict office and indicate whether the closure is temporary or permanent.
Part 75—Underground Coal Mines. Mandatory Safety Standards	75.1204	Within 60 days of (a mine's) permanent closure or abandonment, mine operators must file a copy of the mine map, revised and supplemented to the date of closure, with the Secretary of the Interior. The map must be certified by a registered surveyor or registered engineer.
	75.1204-1	The notice of mine closure and copies of the mine map must be filed with the Coal Mine Safety District office.
	75.1711	Mine openings declared inactive or permanently closed or abandoned for more than 90 days shall be sealed.
	75.1711-1	Shaft openings to be sealed shall be capped or filled. Filling shall be for the entire length of the shaft with the first (lower) 50 ft (15 m) being filled with incombustible material. Caps shall consist of 6-in. (152-mm) thick concrete or equivalent and equipped with a vent pipe (2 in. or 50 mm in diameter, and 15 ft or 5 m above the surface).
	75.1711-2	Slope or drift openings shall be sealed with solid, incombustible material for a distance of at least 25 ft (8 m) into the opening.
Part 77—Surface Coal Mines and Surface Work Areas of Underground Coal Mines—Mandatory Safety Standards	77.215.4	MSHA's District Manager shall be notified in writing when a refuse pile is to be abandoned. If a hazard is determined to be present, a plan for abandonment shall be submitted by the operator and approved by the District Manager. The plan shall include a schedule for its implementation and describe provisions to prevent burning and future impoundment of water and provide for major slope stability.
	77.216-5	Prior to a mine's abandonment, an abandonment plan for water, sediment, or slurry impounding structures shall be submitted by the operator and owner and approved by MSHA's District Manager. The plan shall include a schedule, a provision to preclude future impounding, and provide for slope stability.

Table 8.7.2. Federal Regulations Applicable to Mine Closure, Sealing, and Abandonment, Office of Surface Mining Reclamation and Enforcement, *Code of Federal Regulations,* Chap. 30

Regulation	Paragraph	Description
Part 715—General Performance Standards	715.13	All disturbed areas shall be restored in a timely manner to conditions that are capable of supporting the uses the lands were capable of before mining or to higher or better uses.
	715.14	Postmining graded slopes must approximate the premining natural slopes (approximate original contours). Certain exceptions, such as for mountaintop removal or leaving permanent impoundments, may be approved.
	715.15	The permittee must plan and conduct reclamation operations to minimize disturbance to the prevailing hydrologic balance in order to prevent long-term adverse changes in the hydrologic balance. Changes in water quality and quantity, both surface and groundwater, shall not affect the postmining land use. If pollution can be controlled only by treatment, the permittee shall operate and maintain the necessary water treatment facilities for as long as treatment is required. Groundwater recharge capacity shall be restored to approximate premining recharge capacity. The permittee shall be responsible for monitoring to ensure conformance.
	715.18	All dams shall be removed and the disturbed area regraded, revegetated, and stabilized unless the regulatory authority approves retention of such dams as part of the postmining land use plan.
	715.20	The permittee shall establish on all land that has been disturbed a diverse, effective, and permanent vegetative cover of species native to the area or species that will support the postmining land use.
Part 717—Underground Mining—General Performance Standards	717.14	Upon completion of the underground mining, road cuts and mine entry area cuts shall be regraded to approximate original contours.
	717.17	The permittee must plan and conduct reclamation operations to minimize disturbance to the prevailing hydrologic balance in order to prevent long-term adverse changes in the hydrologic balance. Changes in

Table 8.7.2.—cont.

Regulation	Paragraph	Description
		water quality and quantity, both surface and groundwater, shall not affect the postmining land use. If pollution can be controlled only by treatment, the permittee shall operate and maintain the necessary water treatment facilities for as long as treatment is required. Groundwater recharge capacity shall be restored to approximate premining recharge capacity. The permittee shall be responsible for monitoring to ensure conformance.
	717.18	All dams shall be removed and the disturbed area regraded, revegetated, and stabilized unless the regulatory authority approves retention of such dams as part of the postmining land use plan.
	717.20	The permittee shall establish on all land that has been disturbed by mining operations a diverse, effective, and permanent vegetative cover capable of self-regeneration and plant succession and adequate to control soil erosion. Introduced species may be substituted for native species if approved by the regulatory authority.
Part 780—Surface Mining Permit Applications—Minimum Requirement for Reclamation and Operation Plan	780.18	Each permit application shall contain a plan for reclamation of the lands within the permit area. This plan is to be followed during the closure of a mine.
	780.20	Each permit application shall include a plan that includes steps to be taken during reclamation to minimize disturbance to the hydrologic balance within the permit area and adjacent areas, to prevent material damage outside the permit area, to meet federal and state water quality laws and regulations, and to protect the rights of present water users.
	780.23	Included in the reclamation plan shall be a description of the proposed postmining land use, including a discussion of its utility and capacity to support alternative uses and the relationship of the proposed use to existing land use policies and plans.
	780.25	Each reclamation plan shall include timetables and plans to remove ponds, impoundments, banks, dams, and embankments, if appropriate.
Part 784—Underground Mining Permit Applications—Minimum Requirements for Reclamation and Operation Plan	784.13	Each permit application shall contain a plan for reclamation of the lands within the permit area. This plan is to be followed during the closure of a mine.
	784.14	Each permit application shall include a plan that includes steps to be taken during reclamation to minimize disturbance to the hydrologic balance within the permit area and adjacent areas, to prevent material damage outside the permit area, to meet federal and state water quality laws and regulations, and to protect the rights of present water users.
	784.15	Included in the reclamation plan shall be a description of the proposed postmining land use, including a discussion of its utility and capacity to support alternative uses and the relationship of the proposed use to existing land use policies and plans.
	784.16	Each reclamation plan shall include timetables and plans to remove ponds, impoundments, banks, dams, and embankments, if appropriate.
Part 800—Bond and Insurance Requirements—For Surface Coal Mining and Reclamation Operations Under Regulatory Programs	800.13	Performance bond liability shall be for the duration of the mining and reclamation operation and until successful revegetation or until achievement of reclamation.
	800.14	The amount of bond shall be sufficient to assure completion of the reclamation plan by the regulatory authority in the event of forfeiture.
	800.17	The period of bond liability shall last until all reclamation, restoration, and abatement work has been completed.
	800.40	The applicant may file an application for release of all or part of a performance bond after the applicant has completed any part of the reclamation activities. A newspaper advertisement stating that a bond release has been requested shall be placed by the operator. The advertisement shall run once a week for four weeks in a local newspaper of general circulation. The regulatory authority may release all or part of a bond when it is satisfied that all reclamation or a phase of reclamation is accomplished.
Part 816—Surface Mining Activities—Permanent Program Performance Standards	816.11	Signs and markers identifying the mine and permit numbers shall be retained and maintained until after the release of all bonds for the permit area.
	816.13	When no longer needed for monitoring or other purposes, each exploration hole, other drilled holes, and other exposed underground openings shall be capped, sealed, backfilled, or otherwise properly managed.

Table 8.7.2.—cont.

Regulation	Paragraph	Description
	816.49	A permanent impoundment of water may be created if it is designed for permanent use, will not result in the diminution of quality and quantity of water utilized by adjacent landowners, and will be suitable for approved postmining land use.
	816.132	Persons who cease surface mining activities shall close, backfill, or otherwise permanently reclaim all affected areas. All underground openings, equipment, structures, or other facilities not required for monitoring, unless approved as suitable for postmining land use, shall be removed and the affected area shall be reclaimed.
	816.133	All disturbed areas shall be restored in a timely manner to conditions capable of supporting the uses they were capable of supporting before mining or to higher or better uses.
	816.150	A road not to be retained for use under an approved postmining land use shall be reclaimed immediately after its use for mining and reclamation operations ceases.
Part 817—Underground Mining Activities—Permanent Program Performance Standards	817.15	When no longer needed for monitoring or other purposes, each shaft, drift, adit, tunnel, exploration hole, entry way, or other opening shall be capped, sealed, backfilled, or otherwise properly managed.
	817.48	A permanent impoundment of water may be created if it is designed for permanent use, will not result in the diminution of quality and quantity of water utilized by adjacent landowners, and will be suitable for approved postmining land use.
	817.56	Before abandoning a permit area or seeking bond release, the operator shall ensure that all temporary erosion and sedimentation control structures are removed and reclaimed and that all permanent sedimentation ponds, diversions, impoundments, and treatment facilities meet the requirements of the *Code of Federal Regulations,* Chap. 30, Pt. 817.
	817.132	Persons who cease underground mining activities shall close, backfill, or otherwise permanently reclaim all affected areas. All underground openings, equipment, structures or, other facilities not required for monitoring, unless approved as suitable for postmining land use, shall be removed and the affected area shall be reclaimed.
	817.133	All disturbed areas shall be restored in a timely manner to conditions capable of supporting the uses they were capable of supporting before mining or to higher or better uses.
	817.150	A road not to be retained for use under an approved postmining land use shall be reclaimed immediately after its use for mining and reclamation operations ceases.

Table 8.7.3. Federal Regulations Applicable to Mine Closure, Sealing, and Abandonment, Environmental Protection Agency, *Code of Federal Regulations,* Chap. 40

Regulation	Paragraph	Description
Part 401 —General Provisions	401.12	Requires achievement of effluent limitation for point sources. It is generally the view of the EPA that the effluent limitations apply until the point source is eliminated.
Part 434—Coal Mine Point Source Category	434	Provides effluent limitations for point discharges of various categories of coal mines, coal preparation plants, and associated areas.
Part 430—Mineral Mining and Processing Point Source Category	436	Provides effluent limitation for point discharges of various categories of mineral mining.

Open pit mines often may be temporarily closed since the selling price of the commodity being produced can fluctuate greatly. Past mining methods called for mine overburden to be totally removed and placed in a designed disposal site. Backfilling the pit with the previously disposed waste rock is not normally done as it would be economically disastrous to the mining company. Backfilling of the extreme low areas to eliminate any ponded water may, however, be appropriate. Grading and vegetating pit slopes is also important for ground stabilization reasons.

Quarries: *Quarries* are defined as "open or surface workings, usually for the extraction of building stone, slate, limestone, etc." (Thrush, 1968). Quarries normally sell most of the material mined and therefore leave little waste material for filling in the excavation.

The closure practices employed to achieve effective abandonment include regrading to eliminate hazardous highwalls and revegetation. Steep highwalls can sometimes be removed by "shooting down the highwall." This method (Fig. 8.7.1) can inexpensively reduce the grade and effectively remove a highwall. The regraded area could then be covered with soil and revegetated.

Novel ideas on reclamation are being developed by the the quarry industry. Because many sites are located near urban

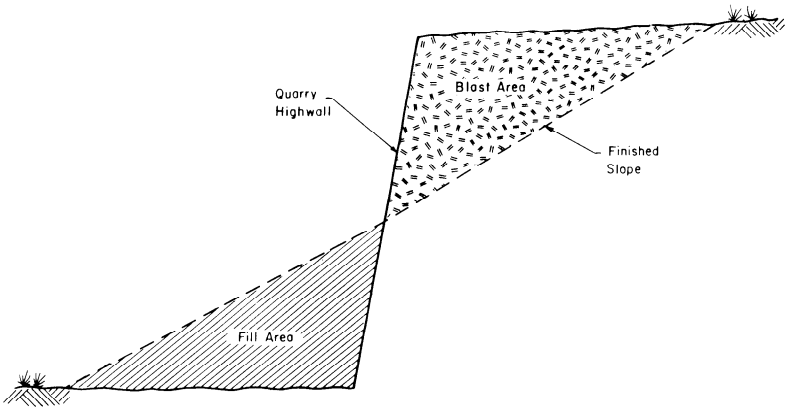


Fig. 8.7.1. Typical section—shooting down the highwall.

areas, landscape architects have become involved with mine planning to integrate the quarry site with existing communities (Culbertson et al., 1988). Three-dimensional simulation by computers is becoming increasingly popular. The view of postmining land is important in areas of high public visibility. In areas close to large population centers, some quarry sites have planned the reclamation to include a lake surrounded by a housing project in the lower parts of the quarry, thus increasing the postmining land value.

Surface Coal Mines: A reclamation plan must be approved prior to the opening of a *surface coal mine.* This plan must be followed when the mine is closed. It is standard practice to submit a reclamation schedule to regulatory agencies within a few months after a decision is made to close a mine permanently. Normally, the backfilling of cuts and the restoration of the surface is required.

Placer Mines: The term *placer* is applied to deposits of sand, gravel, and other detrital or residual material containing a valuable mineral that accumulated through weathering and mechanical concentrating processes (Wells, 1969).

Currently, there are no federal regulations that apply to the closure of placer mines. It is recommended that regulatory agencies be contacted to determine if the project site is subject to any new regulations. Most areas in the United States that are subject to placer mining are on federal or state lands. Reclamation and closure practices for each placer mine site should be discussed and agreed upon prior to leasing the property.

8.7.2.2 Mine Facility Removal

In accordance with mine reclamation regulations, all associated facilities must be removed unless they serve a useful purpose in the postmining land use. These facilities include buildings, material handling systems (conveyors, rail lines, transfer stations, storage bins, docks, etc.), electrical lines, transformers, substations, pipelines, roadways, drainage ponds, and drainage channels. Waste disposal areas must be reclaimed, and any hazardous material must be removed from the site and disposed of at a hazardous waste disposal facility. The following sections discuss certain aspects of removing these facilities.

Demolition and Salvage of Structures: A complete inventory of all available equipment, parts, and supplies should be made as soon as a decision to close a mine is made. From this list, the dispensing of each reusable or salable item can be chosen. Some items could be sent to another mine that is owned by the company. Attempts to sell the remaining items of value should be made. Items can be sold:

1. To a salvage company (usually at "scrap prices").
2. Individually, grouped by bid, or grouped by negotiated price.
3. By public or private auction (auctioneer fees normally range from 5 to 10% of the sale)

For removal of buildings and other structures, a demolition and disposal contractor should be hired. A specialist in this type of work is likely to be less expensive than a mining company performing the removal itself. If enough materials such as copper and steel are salvageable, the contractor may do the project at no cost or even pay the mining company for the salvage rights. The mining company should develop a demolition specification to be agreed to by the contractor. A sample demolition specification, as used by the West Virginia Dept. of Energy on an abandoned mine site demolition project, follows (Anon., 1988a).

"DEMOLITION: Demolition of existing structures shall be performed using standard construction equipment wherever practical. Demolition operations shall be performed with the utmost care not to endanger life or property. The contractor shall be responsible for analyzing all of the structures to be razed so that demolition operations are performed in a manner which results in a total and safe collapse of the structures while maintaining the safety of construction laborers, equipment operators, and vehicular traffic along all public roads.

DEBRIS REMOVAL: All concrete, concrete block and timber, remnants, metal scrap, equipment, and other debris shall be removed from the project area. All foundations are to be completely removed, and the areas regraded to the final ground surfaces shown on the plans, or to the approximate original ground surface.

DEBRIS DISPOSAL: All concrete, concrete block, timber, metal scrap, structural remnants, equipment, garbage and demolition debris shall become the property of the contractor and shall be salvaged or buried within proposed embankment. Onsite burial of noncombustible materials in an approved area is permissible provided a minimum of 2 ft (0.6 m) of natural soil fill is placed over the buried material and provided that the concentration of debris to be buried in any one area is not excessive.

REGRADING: All areas where structures, foundations, equipment, etc., have been demolished and removed shall be regraded. The approximate limits of regrading are shown on the drawings. The slopes shall be regraded to form stable, uniform slopes which conform to the natural slopes in the area and promote proper drainage of surface runoff into natural drainage ways. Upon completion of regrading, the slopes shall be revegetated."

Waste Disposal Areas: Mine wastes that are placed in dry disposal areas can be closed after the site is graded for proper

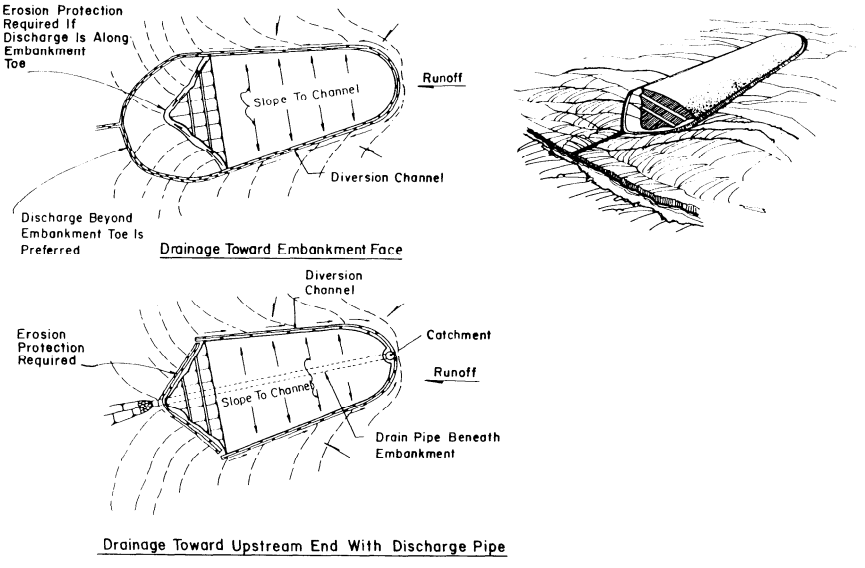


Fig. 8.7.2. Typical final drainage pattern, valley fill disposal site (Anon., 1973).

drainage, covered with soil, and revegetated. Because most waste sites consist of elevated piles, the piles must be left with stable slopes to reduce the potential for sliding. The final grading should be done in a manner that reduces water infiltration into the disposal site so that the potential for toxic leachate generation and surface erosion can be minimized. Fig. 8.7.2 shows a typical layout and grading pattern for a valley fill disposal site. The following two paragraphs are excerpted from the US Department of the Interior's *Engineering and Design Manual for Coal Refuse Disposal Facilities* (Anon., 1975a):

"The final grading of the coarse (dry) refuse would take on a convex or ridgelike configuration with some precipitation running over the first terrace of the refuse slope. However, the bulk of the surface runoff from the crest would flow into diversion ditches around the fill."

"In the instance of an elevated ridge or valley-dump type of facility, the final grading and drainage plan of the crest will have a concave configuration with subsurface drain inlets placed at low point(s). All surface runoff will thus be directed away from the edge of the slope face."

Toxic leachate from waste piles must be eliminated prior to final abandonment of a site. If this is not possible, then a means to treat the water discharge to meet EPA standards must be maintained until the standards can be met and the discharge point eliminated from the EPA's list of point discharges.

Slurry waste disposal impoundments normally are closed by breaching the embankment, letting the material solidify through drying, regrading the surface to drain, covering with soil, and revegetating. Some slurry disposal areas have recently been successfully reclaimed as wetlands (Nawrot et al., 1987). This approach provides new habitat for wildlife and, if appropriate, can reduce closure costs.

Utilities and Roadways: Unless included for a postmining use or for postmining maintenance, electrical facilities such as power lines, substations, and pipelines should be removed during the closure of a mine. Electrical power lines and substations can sometimes be sold to local utilities or other local industries but must remain in service until electrical power is no longer needed at the mine site.

Aboveground pipelines should be dismantled, removed from the site, or buried on site. Underground pipelines can sometimes be capped and abandoned in place unless local regulations specifically require their removal.

Roadways are to be removed and revegetated when they are no longer needed. This can be accomplished by scarifying the surface and regrading to blend the mine roadway into the surrounding landscape. Topsoil may be required to cover the road base material. However, most regulatory agencies will allow roadways to remain if the landowner requests their use for access and to promote the postmining utilization of the property. Roadways can also be used for access to the property during postmining maintenance activities until the reclamation bond is released.

Drainage Facilities: Sedimentation control ponds and ditches should remain active and be maintained for a few years after the mine is closed until the revegetation of the site can successfully control erosion. After their use for erosion and sedimentation control, ponds and ditches can be removed by regrading them to contours that match the surrounding landscape.

Removal of Hazardous Materials: During the operation and particularly during the closure of a mine, the mining company's liabilities with regard to hazardous substances under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (Superfund) must be considered (see Chapter 3.4). Although there are a few exceptions, most mining wastes are not currently considered hazardous by the EPA.

Haller (1987) reports that, "the law (Superfund) provides that the owners and operators of mining sites, together with those who transport hazardous substances to such sites, can be held jointly and severally liable for the cost of cleaning up the site." If a site becomes listed by the EPA as a Superfund site, a cleanup agreement will have to be negotiated between the mining company (or whoever is deemed liable) and EPA.

To close and abandon a mine site that is not listed on the Superfund list is more common. During the closure operation, the mine operator must investigate the site to determine whether there are any hazardous substances on site. Engineers experienced with performing environmental assessments of properties should be retained to make this determination. Hazardous substances most commonly found include asbestos used as building and pipe insulation, PCBs used in electrical devices, and solvents used as cleaners. Areas that had been used as trash disposal areas during the mine operation should have the soil sampled to verify if any hazardous materials leached into the ground.

If contamination is found, a study should be performed by a qualified engineer to verify the degree of contamination. Any

potentially contaminated soils must be adequately sampled to determine whether any action is required or if the soils can be left in place. If the levels of contamination are relatively high, then removal and offsite disposal or onsite treatment of the soils may be required. If hazardous substances are required to be transported offsite, a licensed hazardous waste contractor should be hired to remove the material from the site and transport it to a licensed hazardous waste disposal site. The owner should verify that the contractor and proposed disposal area are currently meeting all regulatory requirements, because if the wastes are spilled enroute to the disposal site or disposed of improperly, the owner may still be held responsible.

8.7.2.3 Underground Mines

Equipment Salvage: Prior to the closure of a mine, the operator should decide whether some equipment (parts, supplies, etc.) could be economically removed from the mine and sold or used elsewhere by the operator. An inventory of available equipment and materials should be made. To assess whether a salvage operation is economical or not, a cost estimate for the removal of each piece of equipment should be made and compared with its resale value. According to Brezovec and Heges (1986), difficult-to-move equipment, such as a coal mine longwall unit, is normally abandoned at a lower cost than the cost to recover the machinery unless, of course, a sure buyer has been found. Mobile equipment such as trucks and continuous miners can generally be sold for more than the cost of removing them. Underground cables that contain a large quantity of copper often are salvagable.

As stated in the previous section, some equipment that may contain hazardous materials must be either decontaminated or removed and disposed of at a hazardous waste disposal site. Inside mines, hazardous materials are generally limited to electrical equipment that contains PCBs.

Hydrology Analysis: Prior to designing any mine seals, the hydrology of the mine must be considered. OSMRE regulations require the completion of a hydrology analysis before permitting any new coal mines. These regulations have essentially prevented up-dip mining in acid-producing coal seams where the mine opening is at a lower elevation than the mine reserves. These regulations were adopted to minimize the impact of postmining water discharge.

A hydrology analysis is required to determine if a hydraulic head will be placed on the mine seal after closure. A crude method of calculating the hydraulic head is to subtract the mine opening elevation from the highest elevation of coal extraction. This method may be acceptable to some regulatory agencies, but it does not consider the potential for additional hydraulic head due to groundwater above the mine. Consideration of the potential hydraulic head associated with groundwater can, however, be very complex. To predict groundwater impacts accurately, hydrogeologists utilize information such as well records, geology, and surface topography to model the groundwater. Groundwater monitoring wells or piezometers may be necessary to monitor the groundwater levels in the mine's vicinity.

Ventilation Planning: During the closure of an underground mine, the shutdown of the mine's ventilation system must be well planned, particularly in gassy mines with water conditions. The ventilation shutdown plan needs to be reviewed on a mine-by-mine basis. The engineer must plan for the systematic shutdown of the system to keep all of the active work areas ventilated and safe from harmful or explosive gases. Regulatory agencies will often require this ventilation plan prior to permitting the closure activities.

For the final sealing of mine openings, again primarily for gassy mines, ventilation must also be considered. During the filling of shafts, some MSHA districts require remote testing for gas the entire length of the shaft. When a gas problem is found, all work must stop until the gas dissipates.

To seal drift, slope, or adit openings in gassy mines that are accessible, a temporary stopping can be erected beyond the work zone. Ventilation tubing can be extended to near the work area and connected to a fan to blow fresh air into the opening.

8.7.2.4 Revegetation

Revegetation of the surface areas of the mine must be accomplished in accordance with the mine's permit. There is much published information available to assist the engineer in formalizing these procedures for a particular mine. Sources of information include local universities with agricultural and/or mining departments, government agricultural agencies, and the US Bureau of Mines.

References by Williams and Schuman (1987), Lyle (1987), and Vogel (1987) are helpful manuals that can be used for mine revegetation planning.

8.7.3 SEALING OF UNDERGROUND OPENINGS

Previously, mine sealing was generally performed only as a safety precaution. Mining regulations now require sealing to be performed during closure. According to Utah's *Shaft Abandonment Guidelines* (Anon., 1987), the following parameters should be considered in sealing shafts.

1. Eliminate any danger to the health and safety of the general public.
2. Control release of hazardous, acid/toxic-forming materials or gases to the atmosphere.
3. Control the movement of underground water or hydrologic communication.

Before a sealing method is selected, the degree of mine closure must be determined. Potential future geologic or economic value, historic value, hazards, and costs must be considered. The different degrees of mine seals can be considered as follows (Anon., 1980b).

Permanent: A safeguard that would completely seal off abandoned workings and would preclude the rehabilitation and future access to the mine. This would be the case if all the ore reserve has been mined or economics dictate that future profitable operation is not deemed probable.

Temporary: Seals that prevent deliberate or accidental entry into a working while preserving the general condition of the opening for future use. If there is some potential future value that can be gained by maintaining an opening to the mine, then this type of closure method should be used. Methods employed are fencing around shafts, glory holes, adits, or drifts; locked doors for adits, drifts, or slopes; and concrete covers for shafts.

Semi-Permanent: A system of seals that completely seals or otherwise blocks an opening while maintaining the general integrity of the opening. Future access to the workings may be desirable. This method should be employed when there is future economic value, but by employing only the temporary method of closing the opening, a threat to the public may exist such as emission of radon or other gases.

As discussed earlier in this section, a hydrogeologic study must be done prior to selecting a seal type. This study will determine if a hydraulic head could build up behind the seal and estimate what it would be. The estimated hydraulic head must be used in seal design calculations.

Permanent seal types available as described in a Bureau of Mines publication (Adams and Lipscomb, 1984) are as follows.

Dry Seal: A dry seal is constructed by placing suitable material such as cement blocks in mine openings to prevent the entrance of air and water into the mine. A dry seal is suitable for openings where there is little or no flow and little danger of a hydraulic head developing.

Wet Seals: A wet seal prevents the entrance of air into a mine while allowing the mine discharge to flow through the seal. Seals of this type are constructed with a water trap similar to traps used in sinks and drains.

Hydraulic Seals: Construction of a hydraulic seal involves placing a plug in a mine entrance that is discharging water. The plug stops the discharge, and the resultant flooding excludes air from the mine and retards the oxidation of sulfide minerals.

8.7.3.1 Boreholes

Temporary seals on boreholes can consist of a locked cap over a protruding casing. When boreholes are no longer required for mine operation or monitoring purposes, a drilling contractor is usually hired to seal the opening. To permanently seal a borehole, the surface casing and protective cap should be removed to a few feet (meters) below the proposed final surface elevation. A plug must be installed in competent strata as close to the borehole and mine roof interception as possible, either remotely by the drilling contractor or from inside the mine if the location of the plug is accessible. The borehole can then be sealed by filling with a nonshrink cement grout. A pour pipe extending to the bottom of the hole should be utilized when placing the cement grout to assure uniform placement of the grout and eliminate voids. The Pennsylvania Dept. of Environmental Resources (Anon., 1988b) guidelines indicate that grout should be placed to within 2 ft (0.6 m) of the surface, with the remainder being filled with dirt to blend into the surrounding area. Other methods employed are plugging the borehole with a bentonite gel or if the borehole is known to have a grouted casing, a plug at the top and bottom and the remainder being filled with inert material may be sufficient. Fig. 8.7.3 shows two types of borehole plugs.

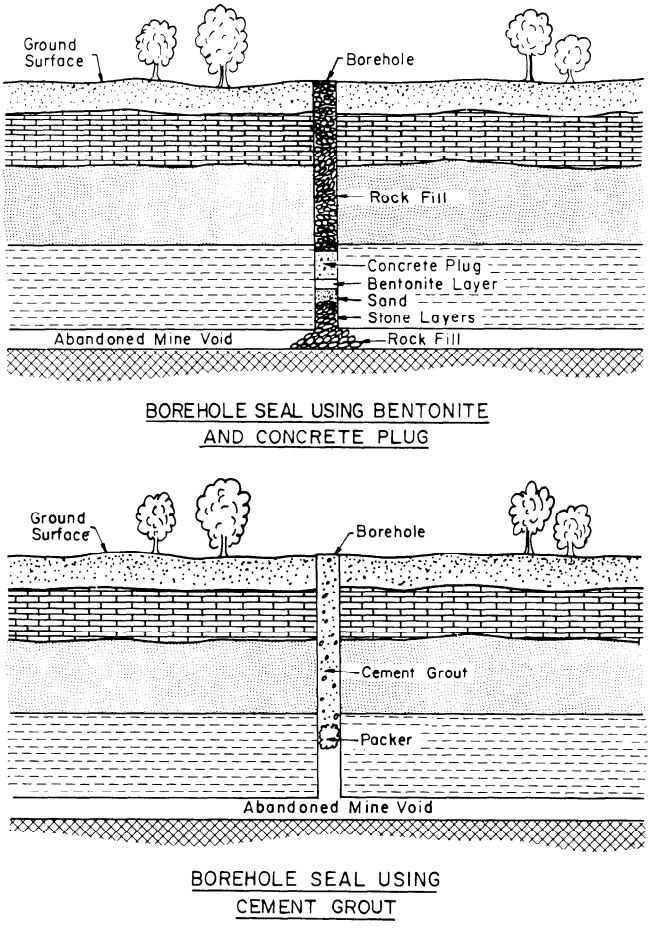


Fig. 8.7.3. Borehole seals (Anon., 1980a).

8.7.3.2 Shafts

For permanent mine closure, OSMRE requires shaft openings into coal mines to be either filled or capped. Filling shall be for the entire length of the shaft with the lower 50 ft (15 m) filled with incombustible material. Caps shall consist of 6-in. (120-mm) thick concrete or other equivalent means and be equipped with a vent pipe (2 in. or 50 mm in diameter, and 15 ft or 5 m above the surface).

Examples of shaft fill plans (where there are no expected hydrologic heads) are presented in Figs. 8.7.4 and 8.7.5. The following is a reprint of the *Shaft Abandonment Guidelines* from the Utah Dept. of Natural Resources (Anon., 1987).

"If there is no hydrologic involvement, small-sized fill material should be interspersed with large debris to allow for void filling. Any debris deposited in this manner should not create voids within the fill that could subside at a later date. Maximum compaction attained during placement is the goal of the selection of the type of backfill material."

"The backfill material selected must be free of acid/toxic-forming and combustible materials. No wood or metal debris should be considered for backfilling of shafts."

"Inorganic and organic silts and clays should be avoided as much as possible. Gravel/sand combinations are the best quality. The material shall be sized so as to minimize voids, i.e., uniformly graded or well-graded. Results of a sieve analysis and engineering soil characteristics shall be submitted to the Division with the reclamation plan about the backfill material."

"In the event of hydrologic movement, consideration must be given to the unique situation and will be handled specifically."

"Caps are recommended at the collar of shafts. A port should be included in the design to monitor the backfilled material. Maintenance of the shaft abandonment should also be included in the plan in the event more backfill may be needed."

To account for settlement in shaft backfill material, the State of Montana (Anon., 1988c) requires that, "shafts be backfilled to a finished elevation above the surrounding natural ground equal to 5% of the shaft depth or as directed by their engineer."

To ensure safety when filling in shafts, the following procedures should be utilized (Hoelle, 1988):

1. Remove surface structures surrounding the shaft.
2. Erect temporary protective fence around work area.
3. Place a sturdy barrier (wheel stop) around the shaft collar.
4. Place a steel cover over the shaft top during idle periods.
5. Monitor for hazardous gases.
6. Place a fence around the site after filling.

An example of a concrete cap used to seal an abandoned shaft is shown in Fig. 8.7.6. Inverted pyramid-shaped caps (or plugs) have also been used successfully to seal abandoned shafts. Dressel and Volosin (1985) describe this method in a US Bureau of Mines publication; it is depicted in Fig. 8.7.7.

If a hydraulic shaft seal is planned in an attempt to eliminate water discharges from a shaft, seals such as the ones shown in Figs. 8.7.8 and 8.7.9 can be designed. These hydraulic plugs must be designed using the same structural design methods as used to design a surface dam.

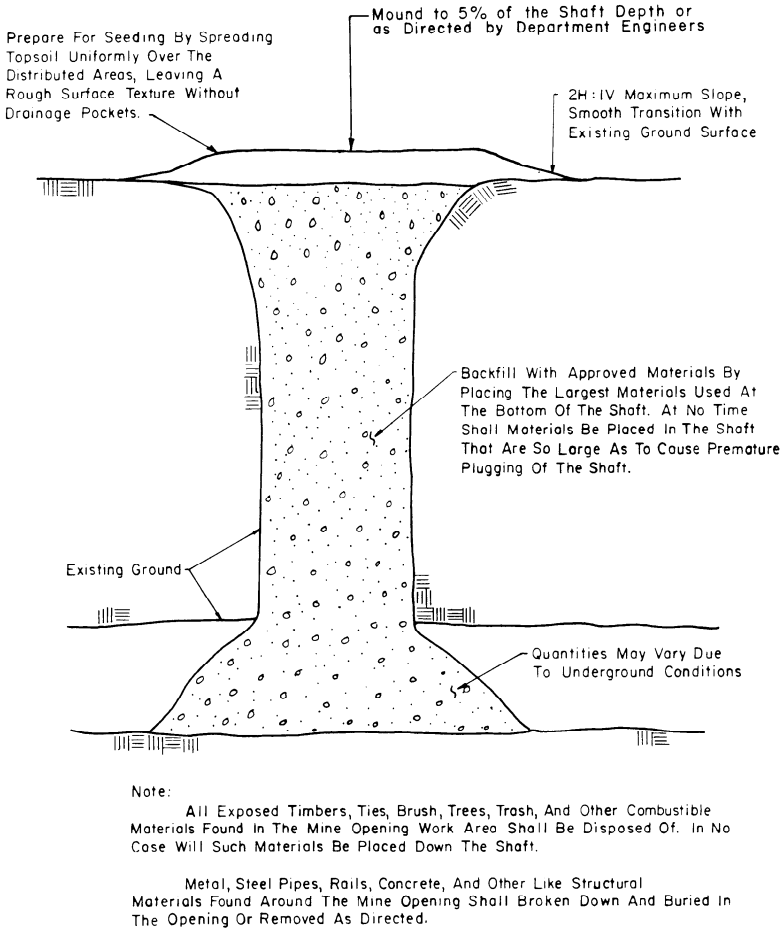


Fig. 8.7.4. Dry shaft seal (Anon., 1988c).

8.7.3.3 Slopes, Drifts, and Adits

Dry Seals: Dry seals can be used to close slopes, drifts, and adits when there is no hydraulic head anticipated at the mine opening. Several different methods can be employed. A method seldom used today is that of simply drilling and shooting down the roof and regrading the area. Fig. 8.7.10 depicts this sealing method. This cannot be done at coal mines because OSMRE requires the opening to be filled by at least 25 ft (8 m) of incombustible material. When the opening is accessible, a concrete wall is often constructed inside the 25-ft (8-m) zone and backfilled. Figs. 8.7.11 and 8.7.12 depict other typical dry seals.

Mine seals placed pneumatically like those depicted in Fig. 8.7.13 are also often used at remote locations (Roberts and Masullo, 1986). Aggregate can be pumped pneumatically through a pipeline from a location accessible to large equipment to the unaccessible mine opening that is to be sealed. If necessary, the aggregate can also be injected with a grout.

Wet Seals: Wet seals are constructed at locations where a hydraulic head is anticipated. A typical wet seal design is shown in Fig. 8.7.14. A variation of a wet seal that is meant to keep air from entering the mine is called an *air seal.* These are constructed at mines where an attempt is being made to limit the oxygen content of the mine atmosphere and thereby limit acidic water production. Fig. 8.7.15 depicts an air seal.

Hydraulic Seals: Current EPA regulations require that all mine water discharges be within acceptable limits. The limits vary according to mine type. After mine closure, mining companies have been required to continue to treat the mine discharge unless it meets the effluent discharge limitations. To eliminate treatment cost and to improve the environment, hydraulic seals have been designed and installed to act as dams and eliminate water discharge. Designing a hydraulic seal to withstand a head of water is not simple. There have been many designs used. Figs. 8.7.16 through 8.7.20 show various types. To be designed and constructed successfully, several design criteria should be met (Chekan, 1985):

1. The bulkhead should be designed to withstand the static forces of hydrostatic pressure rather than the dynamic forces of an explosion.
2. The bulkhead should be constructed from a material, such as concrete, that will resist deterioration by water.
3. The bulkhead should be constructed to be sufficiently thick and properly anchored, and the surrounding strata should be pressure grouted to minimize water seepage.

In addition to the general criteria listed, Chekan also reports that the following factors should be considered before designing and constructing a bulkhead to impound water at a coal mine:

1. The bulkhead should be located in competent ground that is not excessively fractured or broken, preferably in areas of stable ground. However, in most coal mines, ground movements such as roof convergence and floor heave are inevitable, and supplemental roof supports should be installed at the site.
2. The bulkhead, in most cases, should be designed to withstand the maximum hydrostatic pressure that can develop. Practical limits of potential inundation can be determined by plotting the expected mine pool elevations and corresponding ground

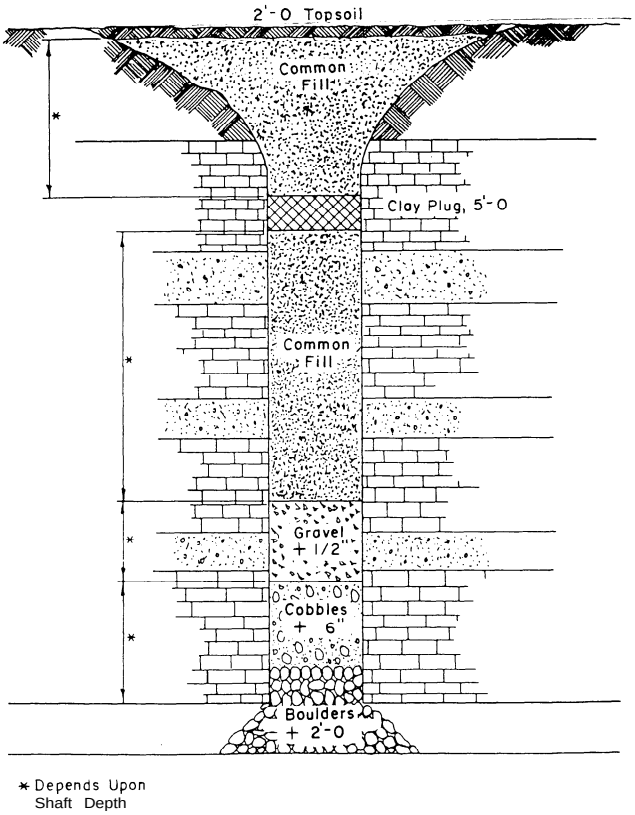


Fig. 8.7.5. Dry shaft seal (Anon., 1980b).

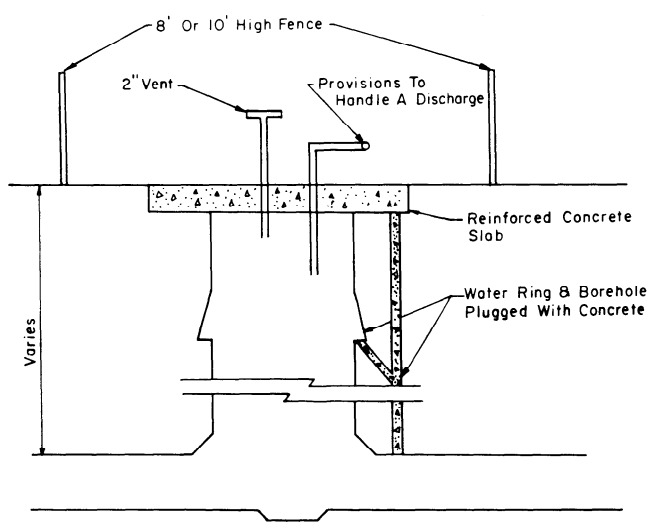


Fig. 8.7.6. Shaft seal using a concrete cap (Anon., 1985).

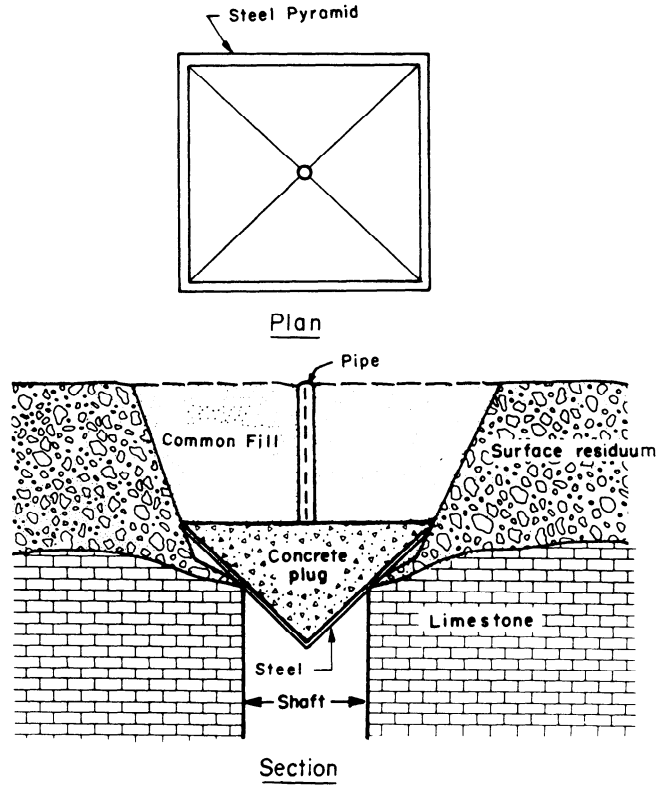


Fig. 8.7.7. Inverted pyramid shaft seal (Dressel and Volosin, 1985).

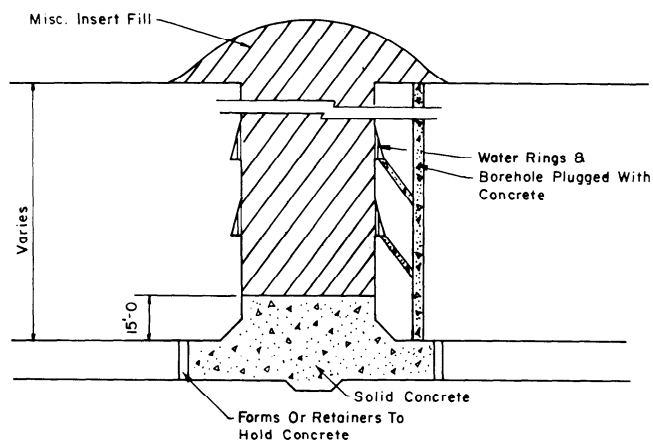


Fig. 8.7.8. Hydraulic shaft seal (Anon., 1985). Conversion factors: 1 in. = 25.4 mm, 1 ft = 0.3048 m.

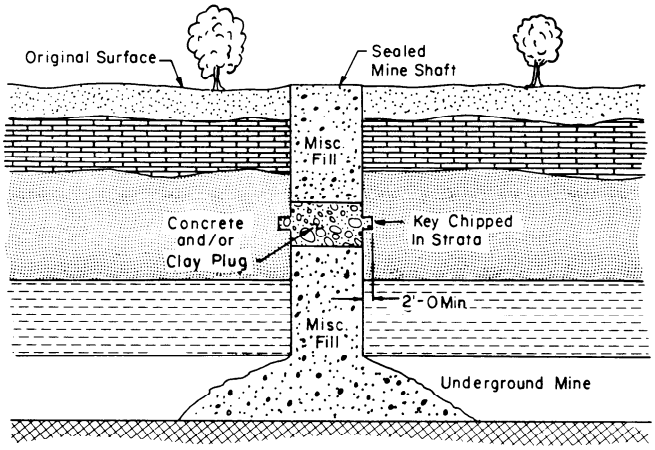
surface elevations on a coal contour map. Areas where excessive water heads may accumulate can then be projected. To convert water head H in feet to hydrostatic pressure P in psi, multiply the water head by 0.434, or $P = 0.434\ H$. In SI units, P in kPa $= 9.82\ H$ in meters.)

3. The concrete for constructing the bulkhead must be properly mixed and placed to achieve acceptable strengths upon curing.

4. Anchorage of the bulkhead to mine roof, ribs, and floor is important and depends on design as well as on strata type and condition. Some design methods rely on the strength of the concrete bearing against the irregularities in the rock surface to provide anchorage. Others require the excavation of trenches.

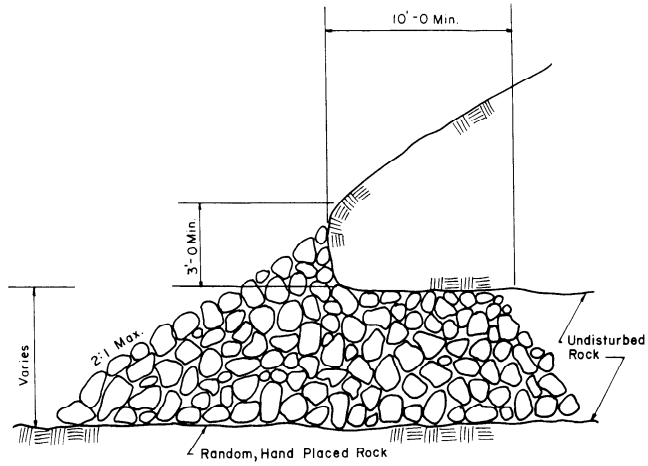
5. Adequate pressure grouting of the immediate strata surrounding the bulkhead is probably the most significant factor in the bulkhead's long-term performance. Deterioration of the anchoring strata by acid-water permeation is a major structural concern, especially if large pressures are anticipated over the life of the bulkhead.

At coal mines having drift entrances that are being sealed using hydraulic seals, it is important that the engineer consider



Conversion factor: 1 ft = 0.3048 m

Fig. 8.7.9. Hydraulic shaft seal (Anon., 1980a).



Conversion factor: 1 ft = 0.3048 m

Fig. 8.7.11. Dry seal of an adit or drift by backfilling rock (Anon., 1988c).

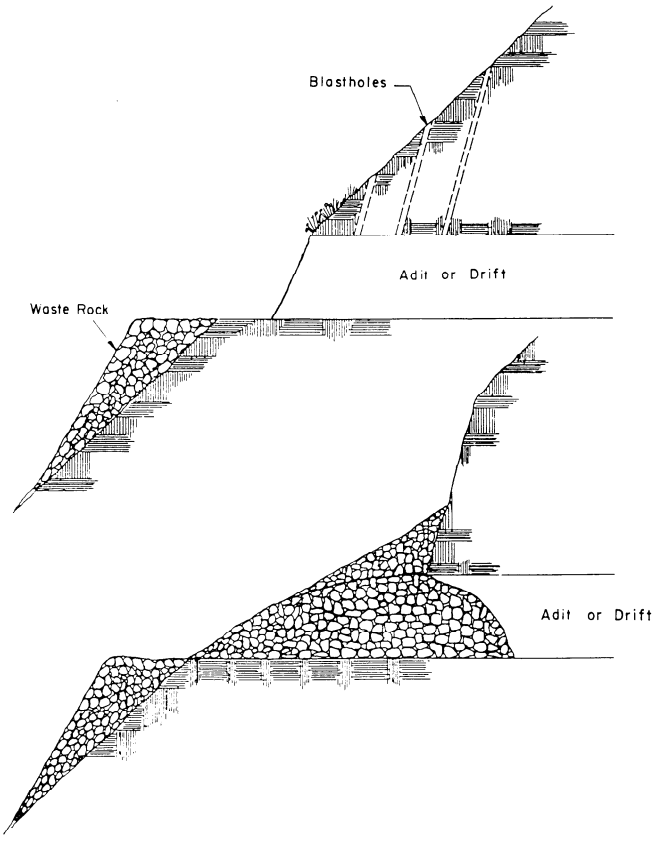
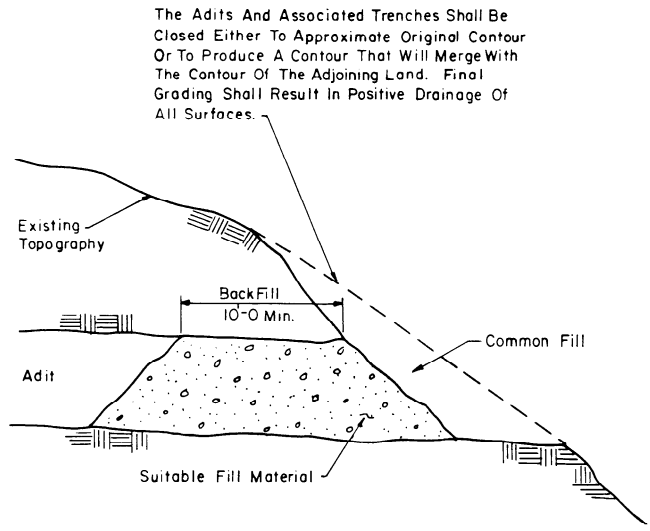


Fig. 8.7.10. Dry seal of an adit or drift by blasting (Anon., 1980a).



Conversion factor: 1 ft = 0.3048 m

Fig. 8.7.12. Dry seal of an adit or drift by backfilling (Anon., 1988c).

what maximum head the coal barriers along the outcrop can withstand without failing. The mine seal may be designed to withstand any water pressure, but the outcrop thickness or mine roof may be of such conditions to permit seepage or a "blowout." Failure could occur due to uplift of the rock strata above the coal barrier or due to lateral translation of the coal barrier.

8.7.4 ABANDONMENT

Only after the mine has been sealed and reclaimed can the mining company abandon the site. Items that must be considered prior to the mining company's legally abandoning the site include postmining land use, maintenance of the site, recovery of reclamation bond, and postmining liability.

8.7.4.1 Postmining Land Use

Permits for new mines require that the planned land use after the mine closes be identified. Normally, the land is returned to a similar premining use or an improved use. After closure of the mine and prior to completely abandoning the site, the mining company must prove to the regulatory agency's satisfaction that the land use is as it was planned to be.

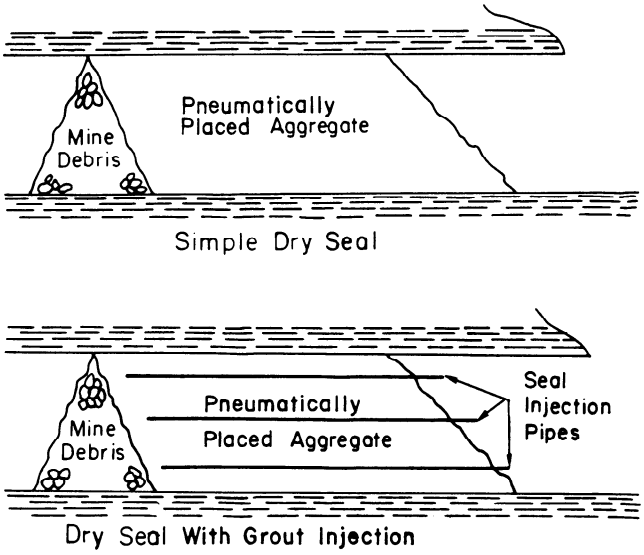


Fig. 8.7.13. Dry seal of an adit or drift by pneumatically placing aggregate (Roberts and Masullo, 1986; *permission: Coal Age*).

Alternative postmining land uses are often requested by mining companies. These alternate uses should be consistent with the land use planning of the local government. If the local land use planners support the alternative land use, no difficulty should be expected in obtaining approval from the mining regulatory agencies, as long as there are no detrimental environmental effects with an alternative use.

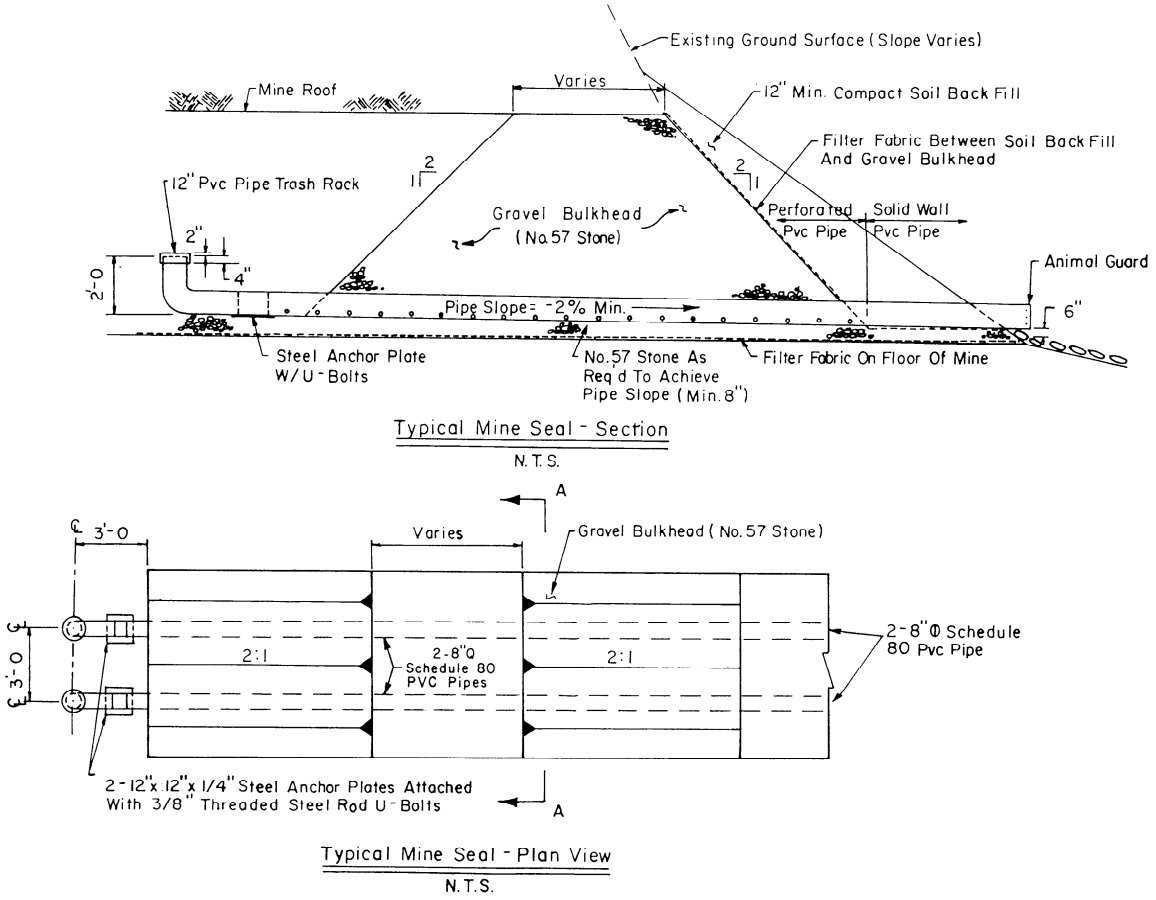
8.7.4.2 Maintenance

After reclaiming a mine site, there will probably be several years of maintenance activity required. This will include periodic inspections of the site to verify that the reclamation is effective. Inspection activities include

1. Verification that mine seals are effective.
2. Cleaning out of sediment and erosion control structures, primarily ponds and ditches.
3. Verification that water discharges are within the permitted effluent limits.
4. Regrading and reseeding of areas, as required.

8.7.4.3 Bond Release

To obtain an operating permit, most mines are required to post a reclamation performance bond that is to be used by a regulatory agency to reclaim an area in the event of forfeiture.



Conversion factors: 1 ft = 0.3048 m, 1 in. = 25.4 mm

Fig. 8.7.14. Wet seal of an adit or drift (Anon., 1988a).

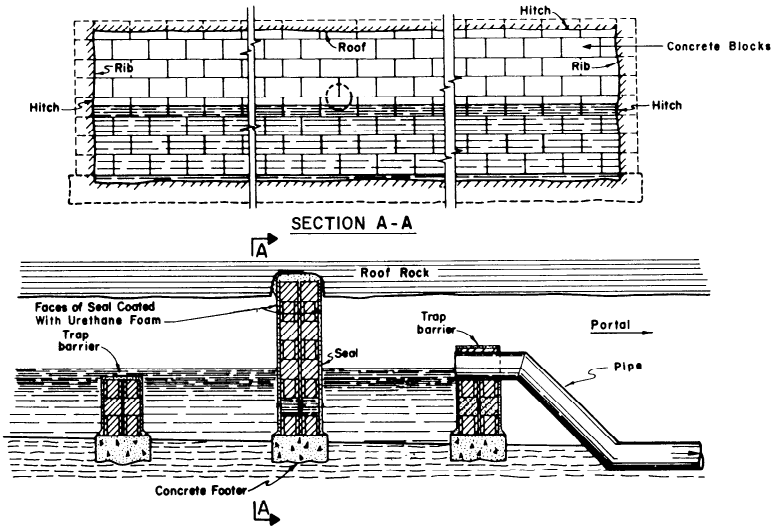


Fig. 8.7.15. Bureau of Mines air seal of an adit or drift (Moebs and Krickovic, 1970).

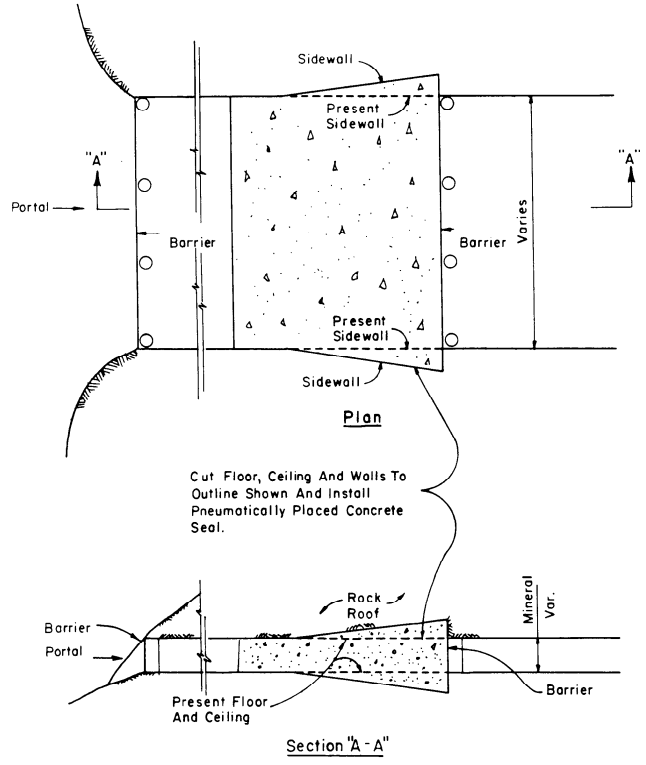


Fig. 8.7.16. Hydraulic seal of an adit or drift using gunite (Anon., 1973).

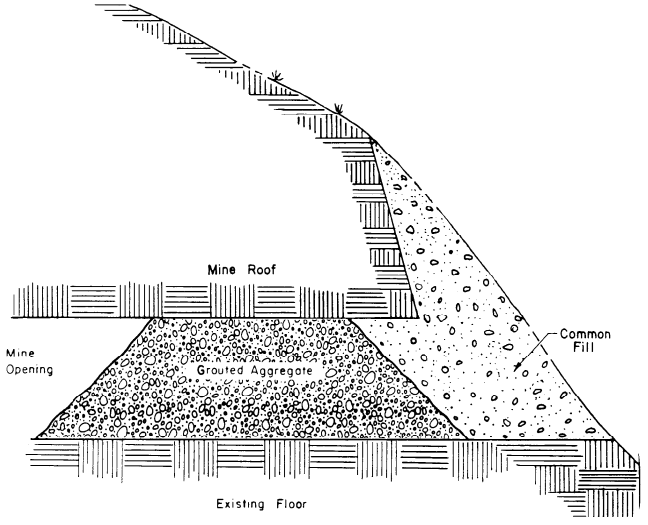


Fig. 8.7.17. Hydraulic seal of an adit or drift using grouted aggregate.

When a mining company has successfully reclaimed the closed mine (or a portion thereof), it may apply for the release of the applicable bond. OSMRE regulations for coal mines specify that the bond is not to be released until the reclamation activity has been completed and revegetation is successful. Verification that the revegetation is successful can often take several growing seasons.

Each regulatory agency may have its own procedure to obtain the release of a reclamation bond. An example of a bond release procedure (that can be considered typical) is the following procedure utilized by the Pennsylvania Dept. of Environmental Resources (Anon., 1985).

On completion of the appropriate stage of reclamation, the operator may file a completion report and request a bond release. Completion reports may be filed only when the appropriate stage of reclamation is completed. The completion report may be filed on either a designated portion or all of the permit area, as appropriate, and only at those times of the year which permit the Department to properly inspect the area.

Bond Release Procedure—Step 1. Action: The application must be examined for completeness, then logged and distributed for office and field review. (If the application is submitted during times of the year when an inspection cannot be made, the operator must be notified that the application is being held until the inspection can be made.)

A field inspection notice must be issued to the operator and the surface owner, agent, or lessee. The notice must be issued and received prior to the field inspection and within a reasonable time of the inspection so that the operator or landowner may participate in the inspection. Notice to the surface owner, or

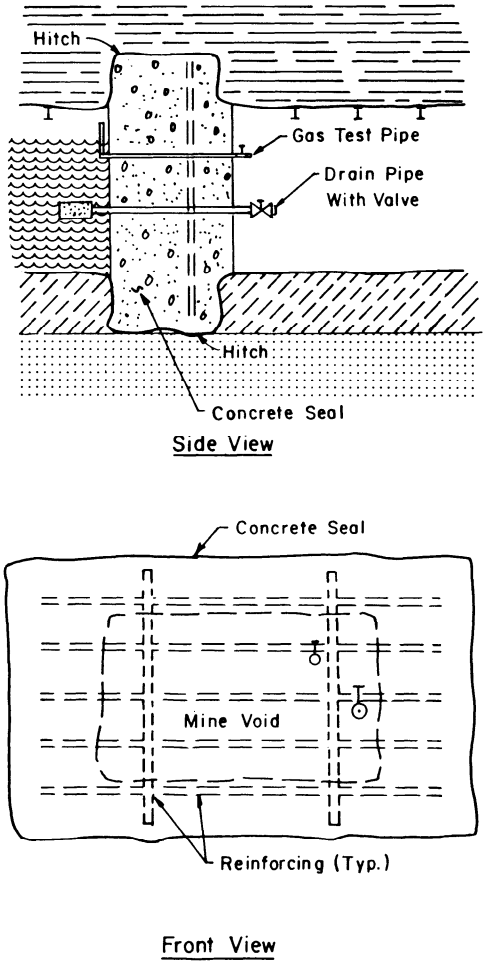


Fig. 8.7.18. Hydraulic seal of an adit or drift using a single concrete bulkhead (Garcia and Cassidy, 1938).

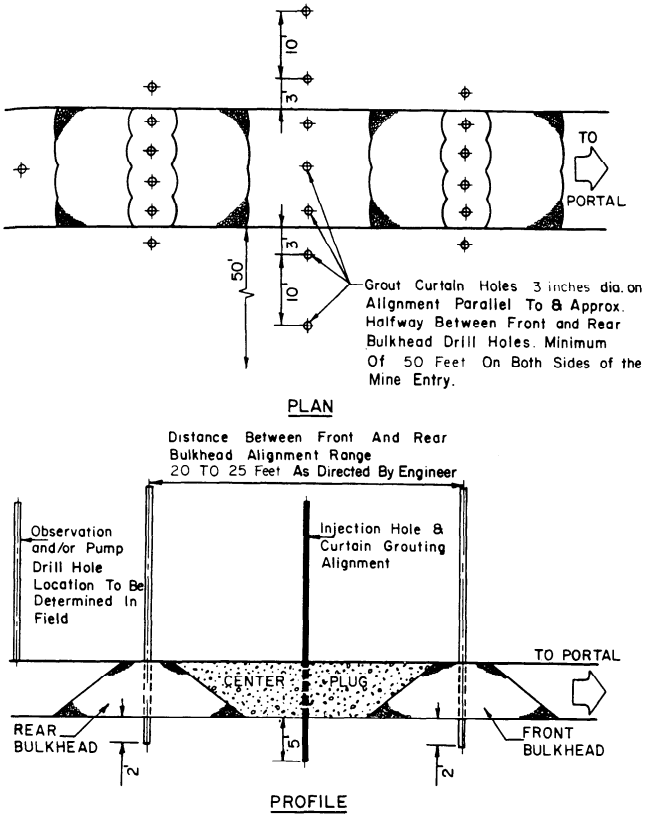


Fig. 8.7.19. Hydraulic seal of an adit or drift using a grout curtain with double bulkhead seal (Foreman and McLean, 1973). Conversion factor: 1 ft = 0.3048 m.

agent or lessee of the surface owner, will be based on the completion report.

Step 2. Action: Verify that the application, public notice advertisement and public notice letters are proper.

Step 3. Action: Field review of area. When possible, the field inspection should be scheduled at the same time as the monthly inspection and also documented as a monthly inspection.

Step 4. Action: Conduct an informal conference if requested.

Step 5. Action: Finalize review of the completion report and issue the final determination to the operator. A copy of the final determination must also be sent to the local municipality, each party that submitted written comments or objections, and each party that attended the informal conference. If a bond release is approved, the amount of bond release must be verified.

8.7.4.4 Postmining Liability

Even after the mine has closed and reclamation activities are completed, the mining company's liability may not end. Two primary potential problems are water treatment and subsidence. Each mine's development and operation plan and mining methods should be instituted so that they limit the mine's susceptibility to postclosure costs. The costs can be substantial and could affect the economic condition of the mining company.

Water Treatment: If there is water being discharged from the mine site that does not meet the effluent limitations of the current applicable regulations, treatment of the water discharge is required. This treatment may be necessary for many years or even perpetually. Because this cost can be great, future mining methods should include planning either to eliminate a postmining discharge or to assure that the discharge will meet the EPA effluent limitations. Metcalf and Eddy (Anon., 1979) and Reynolds (1982) can be used to assist engineers in the design of water treatment facilities. The US EPA (Anon., 1983) has also published a design manual on the neutralization of acid mine drainage.

Subsidence: OSMRE regulations require coal mine operators to "adopt measures consistent with known technology which prevent subsidence from causing material damage to the extent technologically and economically feasible, maximize mine stability, and maintain the value and reasonably foreseeable use of surface lands; or adopt mining technology which provides for planned subsidence in a predictable and controlled manner. Nothing in this part shall be construed to prohibit the standard method of room and pillar mining."

Although this regulation applies to coal mines only, underground mine operators of noncoal mines may want to do similar planning if they deem their specific situation warrants it. If subsidence does occur following mining and causes material damage to the surface, OSMRE regulations further require the operator to

"1. Correct any material damage resulting from subsidence caused to surface lands, to the extent technologically and economically feasible, by restoring the land to a condition capable

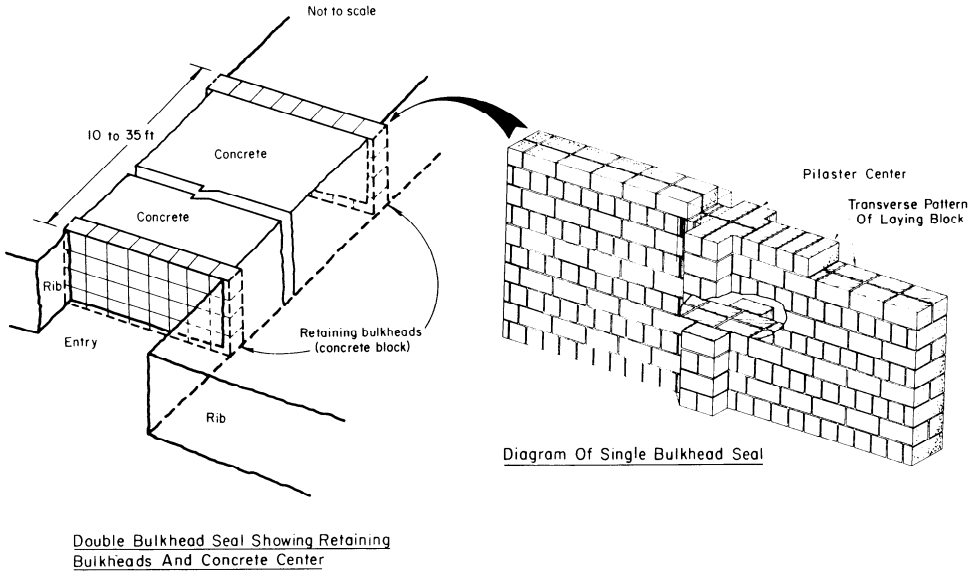


Fig. 8.7.20. Hydraulic seal of an adit or drift using a double bulkhead (Chekan, 1985). Conversion factor: 1 ft = 0.3048 m

of maintaining the value and reasonably foreseeable uses which it was capable of supporting before subsidence; and

"2. To the extent required under applicable provisions of state law, either correct material damage resulting from subsidence caused to any structures or facilities by repairing the damage or compensate the owner of such structures or facilities in the full amount of the diminution in value resulting from the subsidence. Repair of damage includes rehabilitation, restoration, or replacement of damaged structures or facilities. Compensation may be accomplished by the purchase prior to mining of a noncancellable, premium-prepaid insurance policy."

This liability to pay for subsidence-caused surface damage does not leave the mine operator after abandonment of the mine.

Subsidence-related underground coal mining is the inevitable result of high-extraction mining practices and the occasional (relatively infrequent) result of partial extraction mining practices. Mine operators can categorize various portions of their mine into the following:

Planned Subsidence—Represents lowering the ground surface in a manner predictable (within limits) as to areal extent, amount of subsidence, and amount of ground surface distortion as a result of appropriate mine design and mining procedures. Planned subsidence is the result of high-extraction technologies, such as longwall and pillar retreat in coal mines.

Unplanned Subsidence—Represents lowering of the ground surface in a manner that cannot be predicted as to areal extent, amount of subsidence, or amount of ground surface distortion, as a result of failure at mine level of the overburden support system (pillars/mine roof/mine floor) or as a result of the action of other unanticipated causes, such as the piping of unconsolidated sediments into the mine.

Planned Subsidence Prevention—Can be accomplished by utilizing a mining method that provides for permanent ground support. When the percentage extraction from a mine panel is low to moderate, the loads imposed upon pillars by the overburden are generally small in relation to the size of the pillars. In this situation, subsidence of the ground surface is virtually nil and will remain so over the long term.

In planned subsidence or planned subsidence prevention areas, the mining company should be confident that no long-term liability exists. In areas considered to have unplanned subsidence potential, subsidence may occur at an unpredictable time in the future. If any areas in this category exist in a mine being abandoned, and the company has some control over future land use, the company may wish to consider limiting land uses or requiring subsidence resistant designs for future building developments. Insurance against future claims could also be purchased.

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