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Results of Research To Develop Guidelines for Mining Near Surface and Underground Bodies of Water

UNITED STATES DEPARTMENT OF THE INTERIOR

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By Clarence O. Babcock and Verne E. Hooker

UNITED STATES DEPARTMENT OF THE INTERIOR
Cecil D. Andrus, Secretary

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SPECIAL NOTE

The section on mine maps (pages 11-13) is synopsized from existing Federal regulations (30 CFR 75.1200). This section is included to emphasize the importance of mine maps in relation to mining under or near bodies of water and is not intended as an additional mapping requirement or as a proposed amendment to current regulations.

Panel and pillar mining, being used in the United Kingdom, is not yet extensively used in the United States. This system which works well in deep coal, has much less application here, particularly in the eastern part of the country where the biggest tonnage is relatively shallow. The panel width used has been so wide that only deep coal can qualify for mining by this method. However, if this method is imported, as the longwall method was in the past, some guidelines for its use will be available. The method should find use where the coal is at the necessary depth, because higher recovery is possible than with room-and-pillar methods.

RESULTS OF RESEARCH TO DEVELOP GUIDELINES FOR MINING NEAR SURFACE AND UNDERGROUND BODIES OF WATER

by

Clarence O. Babcock [1] and Verne E. Hooker [2]

ABSTRACT

This Bureau of Mines publication presents guidelines for mining near surface and underground bodies of water. The guidelines were based on information developed under contract in three phases of study, as follows: (1) Collection and documentation of data from worldwide sources; (2) application of existing guidelines, foreign, Federal, and State, to case histories of previous inundations; and (3) development of recommended guidelines for underground coal mining near bodies of water aimed at maximum efficient utilization of underground coal resources consistent with minimizing inundation hazards. While the contract guidelines were for the mining of coal seams, they may also be used for mining any tabular sedimentary mineral deposit. Tables are given for the determination of the size of coal pillars needed; for other bedded deposits, similar tables could be determined based on their strength properties.

INTRODUCTION

The need for practical safety guidelines when mining near bodies of water is growing because of increasing mineral demands and an increasing number of water impoundments near mineral resources. Accordingly, the Bureau of Mines generated a program for the development of potential recommended guidelines for mining in close proximity to bodies of water. The objective was maximum efficient utilization of underground coal resources consistent with minimizing inundation hazards.

It should be emphasized that an empirical approach to data collection was used in developing these recommendations. The basic engineering concepts are sound; however, when there is sufficient engineering data or mining experience available, these conservative recommendations should be modified. Further research is under consideration to refine the engineering conditions on which the recommendations are based.

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Two contracts on the subject were initiated in May 1975 and completed in September 1976.[3] Results of the contracts were evaluated and compiled by the authors into a single comprehensive set of recommended technical guidelines relative to surface waters, surface structures, and abandoned workings.

These recommended guidelines cover total extraction by longwall or retreat pillar robbing, partial extraction by room and pillar, partial extraction by panel mining, and a combination of these methods. Some of the important variables involved are the solid rock cover above the coal seam(s), allowable tensile strain at the bottom of the water body, the number of seams that may be mined or restricted, and the allowable proximity of faults, old workings, etc.

SURFACE WATERS

Total Extraction Mining

A total extraction mining system is defined as the extraction of the whole minable thickness of a coal seam or other bedded mineral deposit over a large enough area so that the lateral dimensions in any direction are equal to or greater than the depth of mining. The method of extraction, whether by longwall, continuous, or conventional mining, is not relevant to this definition.

The following guidelines are recommended with respect to total extraction mining. These guidelines require the establishment--by drilling or otherwise--of the thickness of solid rock cover above the proposed total extraction workings. If it is desired to have overlying material(s) other than solid rock cover included in the minimum depth stipulation, it is necessary to demonstrate the nature and permeability of such materials. Where the word "coal" or "seam" is used, it also applies to any bedded mineral deposit.

1. Any single seam of coal beneath or in the vicinity of any body of surface water may be totally extracted, whether by longwall mining or by pillar robbing, provided that for each 1-foot thickness of coal seam to be extracted, a minimum of 60 feet of solid strata cover exists between the proposed workings and the bed of the body of surface water.

2. Where more than one seam of coal exists, all may be worked by total extraction provided that for each 1 foot of the aggregate coal and rock thickness of all seams to be extracted, a minimum thickness of 60 feet of solid strata cover exists between the proposed workings in the uppermost seam and the bed of the body of

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[3] Skelly and Loy (Harrisburg, Pa.). Guidelines for Mining Near Surface Waters (Contract HO252083). BuMines Open File Rept. 29-77, 1977, 190 pp.; available for consultation at the Bureau of Mines libraries in Denver, Colo., Twin Cities, Minn., Pittsburgh, Pa., Spokane, Wash., and Carbondale, Ill.; at the Central Library, U.S. Department of the Interior, Washington, D.C.; at the libraries of the Morgantown Energy Research Center--ERDA, Morgantown, W. Va., and the Training Facility--MESA, Beckley, W. Va.; and from the National Technical Information Service, Springfield, Va., PB 264 728/AS.

K. Wardell and Partners (Newcastle, United Kingdom). Guidelines for Mining Near Surface Waters (Contract HO252021). BuMines Open File Rept. 30-77, 1977, 59 pp.; available for consultation at the Bureau of Mines libraries in Denver, Colo., Twin Cities, Minn., Pittsburgh, Pa., Spokane, Wash., and Carbondale, Ill.; at the Central Library, U.S. Department of the Interior, Washington, D.C.; at the libraries of the Morgantown Energy Research Center--ERDA, Morgantown, W. Va., and the Training Facility--MESA, Beckley, W. Va.; and from the National Technical Information Service, Springfield, Va., PB 264 729/AS.

surface water. When subsidence observations have been carried out and satisfactory calculations of surface tensile strain can be made, any number of seams may be mined by total extraction provided that the maximum cumulative, calculated[4] tensile strain beneath a body for surface water will nowhere exceed 8.75 mm/m (0.875 percent).

3. Where a single seam has already been mined by total extraction in accordance with the provision that for each 1-foot thickness of mineral and rock extracted, a minimum of 60 feet of solid strata cover should exist, no other underlying seam should be mined by total extraction. Where the cover between the two seams is 60 times (or greater) the extractable thickness of the lower seam, such a lower seam should be mined by partial extraction--in accordance with the subsequent guidelines here stipulated--as though the upper seam represented a body of surface water.

4. Where wash or other natural or artificial deposits, which may be highly permeable or which when wet may flow, exist between bedrock and the bed of a body of surface water, these should be excluded from the thickness of solid strata mentioned, except where it has been demonstrated that such wash or other deposits would not be likely to flow when wet and could be considered as impermeable.

5. Where a fault which might connect mine workings with a body of surface water and which has a vertical displacement greater than 10 feet, or an intrusive dike having a width greater than 10 feet, is known to exist or is met with during development, no seam should be totally extracted within 50 feet horizontally on either side of such fault or dike.

Partial Extraction Mining

A partial extraction system is one in which designated pillars are deliberately left unworked for the purpose of giving more or less permanent support to the overlying strata and the land surface. Two such systems are the room-and-pillar first working and the panel-and-pillar system.

Room and Pillar

In the room-and-pillar system of mining about 50 percent of the coal is recovered by two intersecting sets of parallel entries, usually nearly perpendicular to one another. The result is a checkerboardlike array of pillars which systematically support the roof rock. In the following discussion the term "first working" means that the coal is mined by driving the entries, as opposed to "secondary workings" in which the coal left in the pillars is mined to increase recovery.

Minimum Depth of Cover

A minimum thickness of solid strata cover should be left above the coal seam. Both the height and width of the entries and the characteristics of

[4]Calculation procedure is given in the appendix.

the roof beds are significant parameters with respect to expected roof collapse height.

The separate provisions with respect to drifts and tunnels are stipulated because the practicability and cost of supporting and maintaining them would be generally acceptable. In room-and-pillar entries, however, the cost of permanent supports would be exceptionally high and their maintenance would be generally impracticable.

The following guidelines are recommended with respect to a minimum depth of solid strata for room-and-pillar workings.

1. No entry should be driven in any coal seam lying beneath or in the vicinity of any body of surface water where the total thickness of solid strata cover above the seam is less than 5 times the maximum entry width (5s) or 10 times the maximum entry height (10t), whichever is the greater. Where at least one competent bed of sandstone or similar material is present within the solid strata and has a thickness at least 1.75 times the maximum entry width, mining at a lesser cover than 5s or 10t may be considered.

2. In the case of drifts or tunnels beneath or in the vicinity of the body of surface water driven through the strata for the purpose of gaining access to a coal seam, the provision of 10t or 5s should also apply unless drifts or tunnels are permanently supported and are so maintained. In the latter event, however, there should be a minimum solid rock cover of 1.75 times the maximum drift or tunnel width.

Pillar Dimensions for First Workings

The results of observing the behavior of mine pillars underground with respect to stability, of laboratory testing of coal samples, and of theoretical considerations were combined to establish the size of coal pillars needed for safety as functions of coal thickness, depth below surface of the coal seam, and the room width used. In accordance with the results, the following guidelines are proposed with respect to pillar dimensions for room-and-pillar first workings.

1. Where room-and-pillar first working is to be carried out beneath or in the vicinity of any body of surface water and at cover depth greater than the stipulated minimum, the minimum width of pillar should be determined in accordance with tables 1 through 7.[5] An exception is made where specific local data (including relevant and comparable mining experience) exist which demonstrate that a lesser width could be used with safety.

[5]Tables include seams thicknesses of 3, 4, 6, 8, 10, 12, and 14 feet. If other seam thickness data are required, the tabulated value, W, can be obtained by trial and error or numerical methods from the equation $((W+R)/W)^2 1.5D = 1000/\sqrt{H} + 20\ (W/H)^2$, where W, R, H, and D are pillar width, room width, seam thickness, and depth from surface, respectively.

2. Where an upper seam has been mined by room-and-pillar first working in accordance with these guidelines, underlying seams should not be mined--whether by total or partial extraction--except by considering the upper seam as though it were the base of the surface body of water.

3. Where pillar widths are determined in accordance with these provisions, the calculated pillar loading should not exceed the allowable load-bearing capacity of the immediate roof and/or floor beds.

TABLE 1. - Minimum pillar widths for pillar heights of 3 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	12	13	14	-	-
150	15	16	16	17	18
200	17	18	19	20	20
250	19	20	21	22	22
300	20	21	22	23	24
350	22	23	24	25	26
400	23	24	25	26	27
450	25	26	27	28	29
500	26	27	28	28	30
550	27	28	29	30	31
600	28	28	30	31	32

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 2. - Minimum pillar widths for pillar heights of 4 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	14	15	16	-	-
150	17	18	19	20	21
200	20	21	22	23	24
250	23	24	25	26	27
300	25	26	27	28	29
350	27	28	29	30	31
400	29	30	31	32	33
450	30	31	33	34	35
500	32	33	34	35	36
550	33	34	36	37	38
600	35	36	37	38	39

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 3. - Minimum pillar widths for pillar heights of 6 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	17	19	20	-	-
150	22	24	25	26	27
200	26	28	29	30	32
250	30	31	33	34	35
300	33	35	36	37	38
350	36	37	39	40	41
400	39	40	41	43	44
450	41	42	44	45	46
500	43	45	46	47	48
550	45	47	48	49	51
600	47	49	50	51	53

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 4. - Minimum pillar widths for pillar heights of 8 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	21	22	24	-	-
150	27	29	30	32	33
200	33	34	36	37	38
250	37	39	40	42	43
300	41	43	44	46	47
350	45	47	48	49	51
400	48	50	51	53	54
450	51	53	55	56	57
500	54	56	57	59	60
550	57	59	60	62	63
600	60	61	63	64	66

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 5. - Minimum pillar widths for pillar heights of 10 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
100	24	26	27	-	-
150	32	34	35	37	38
200	39	40	42	43	45
250	44	46	48	49	51
300	49	51	53	54	56
350	54	56	57	59	60
400	58	60	61	63	64
450	62	64	65	67	68
500	66	67	69	70	72
550	69	71	72	74	75
600	72	74	76	77	79

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 6. - Minimum pillar widths for pillar heights of 12 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	37	39	40	42	44
200	45	46	48	50	51
250	51	53	55	57	58
300	57	59	61	63	64
350	63	65	66	68	70
400	68	70	71	73	75
450	73	74	76	78	79
500	77	79	80	82	84
550	81	83	84	86	88
600	85	87	88	90	91
650	88	90	92	94	95
700	92	94	95	97	99
720	93	95	97	98	100

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

TABLE 7. - Minimum pillar widths for pillar heights of 14 feet, feet

Depth, feet	Room width				
	16 feet	18 feet	20 feet	22 feet	24 feet
150	41	43	45	47	48
200	51	53	54	56	58
250	58	60	62	64	66
300	66	67	69	71	73
350	72	74	76	77	79
400	78	80	81	83	85
450	83	85	87	88	90
500	88	90	92	93	95
550	93	95	96	98	100
600	97	99	101	103	104
650	102	103	105	107	108
700	106	107	109	111	113
750	109	111	113	115	116
800	113	115	116	119	120
840	116	118	120	121	123

NOTE.--The figures in this table in no way exclude the application of total extraction mining at the appropriate solid strata cover and seam thickness.

Panel and Pillar

The panel-and-pillar system is defined to be one in which a bedded deposit is totally extracted from panels which are of such width in relation to their depth that the main strata can span any one of them with little deflection. Individual extraction panels are separated by abutment pillars designed to sustain the load of the main strata overlying a group of such panels and pillars. The minerals from the panels may be extracted by long-wall mining, or the panels may first be mined by room and pillar and the pillars may subsequently be taken by either continuous or conventional mining methods.

The following guidelines are recommended with respect to panel-and-pillar mining beneath and in the vicinity of bodies of surface water.

1. Where the panel-and-pillar system is to be carried out beneath or in the vicinity of any body of surface water, there should be a minimum solid strata cover thickness of 270 feet or 3p, where p is the width of the panel, whichever is greater.

2. The widths of extraction panels should not exceed one-third the depth of mining, and the widths of pillars between extraction panels should be 15 times their height or one-fifth the depth of mining, whichever is greater.

3. Where more than one seam is to be mined by this system, the panels and pillars in all seams should be superimposed in the vertical direction with the panel widths being determined from the depth to the uppermost seam and the pillar widths being determined by reference to the thickest and/or deepest seam, whichever would give the greater dimension.

4. Where the panel-and-pillar system of mining has been employed in an upper seam, it should not be permissible to mine by total extraction in any underlying seam except by considering the upper one as though it were the base of the surface body of water.

Safety Zones

From observed behavior of rock strata and soil above mined-out regions, a zone is known to exist that will most likely fail if mined, causing flooding of the workings and damage to the surface and to surface structures. From rock mechanics considerations the approximate shape and extent of this zone can be identified. If no risk can be taken, obviously no mining is possible. For many conditions of mining, no damage is likely to occur and mining should be permitted.

Surface Waters

The following guidelines are recommended with respect to safety zones around and beneath bodies of surface water.

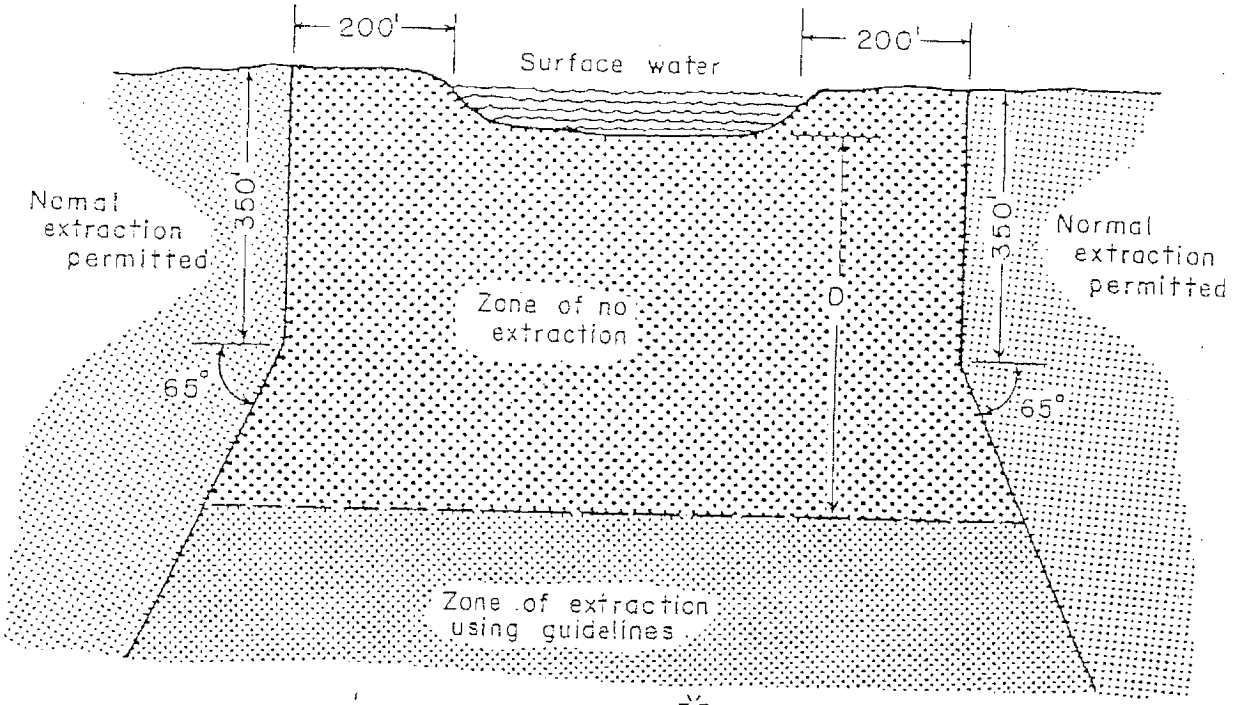
1. Where any body of surface water is present above the potential mine workings, a safety zone around such body of surface water should extend 200 feet horizontally from the high-water mark, or perimeter of the water body, and vertically downward from this point to a depth of 350 feet, then outward at an angle of dip of 65° as shown in figure 1.

2. If mining is considered within such a safety zone, it should be in accordance with the guidelines for mining beneath surface waters.

3. The width of such a safety zone may be increased or decreased if local observations and/or experience justify.

Structures Retaining Water

Since there is always some risk that damage will occur to surface structures by mining, no mining should be done in a safety zone beneath and around



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Room and pillar	5s or 10t
Panel	3p or 270 ft
Total extraction	60t

*Whichever is larger

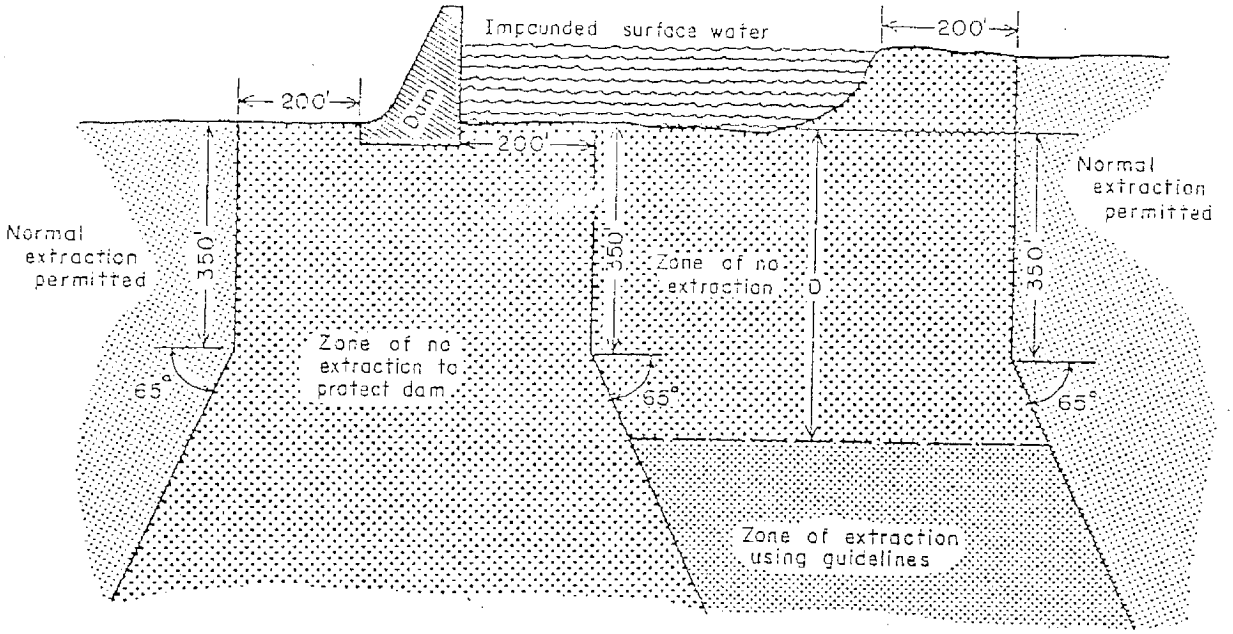
FIGURE 1. - Safety zone beneath body of surface water.

a structure where its failure would cause loss of life, property damage, or damage to water supplies needed for the public welfare. If the consequences of structural failure are not severe, mining may be undertaken.

The following guidelines are recommended with respect to safety zones around and beneath structures the survival of which is important to the public welfare.

1. Where any surface structure is impounding a substantial body of surface water and damage to that structure by mine subsidence effects could lead to a risk of structural failure and prejudice to public safety, no mining should be permitted within the safety zone of such a structure.

2. The perimeter of the structure requiring protection should be established by those responsible for its maintenance and safety. The safety zone around the perimeter of protection should extend outward 200 feet in all directions, then downward for 350 feet, and then outward at a dip of 65° from the horizontal as shown in figure 2. This safety zone is designated as a zone of no extraction. Figure 2 also shows the restriction on mining beneath the impounded water.



0*

Room and pillar	5s or 10t
Panel	3p or 270 ft
Total extraction	60t

*Whichever is larger

FIGURE 2. - Safety zone beneath dam and impounded body of surface water.

3. A greater or lesser distance than that specified in paragraph 2 may be used where local observations and/or experience so indicate.

UNDERGROUND WATERS

Mine Maps

The operator of a coal mine should have in a fireproof repository (located in an area on the surface of the mine chosen by the mine operator to minimize the danger of destruction by fire or other hazard) accurate, up-to-date maps of the mine drawn to scale.

Surface Features

Surface features may be shown directly on the mine map, or on a transparent or translucent sheet, which, when overlain on a map of underground workings, shows true and exact relations of surface features to mine workings and excavations. Surface features to be shown include--

1. Name and address of the mine.
2. Scale and orientation of the map.
3. Boundary lines and names of all surface property owners.

4. Boundary lines of the coal rights pertaining to each mine.
5. All outcrop lines.
6. Topographic features such as hills, ravines, intermittent and permanent streams, bodies of standing waters (with elevations and estimated depths).
7. Location and identification of municipal subdivisions (State, county, townships).
8. Location of all railroads and sidings, highways, and other roads.
9. Location and identification of mine buildings and facilities.
10. Location of all utilities and pipelines.
11. Location and depth of holes drilled for oil, gas, water, or geologic information that penetrate a workable seam.
12. Location of all surface fans.
13. Location of mine openings.
14. The location and description of at least two permanent baseline points coordinated with the underground and surface mine traverses, and the location and description of at least two permanent elevation bench marks used in connection with establishing or referencing mine elevation surveys. Location and description of a permanent bench mark or monument near the main mine opening.

Underground Features

Whether or not combined on the same sheet with surface features, at least one set of maps showing underground features should be composed on the same scale. Pertinent information to be recorded on the mine map should include--

1. Name and address of the mine.
2. Scale and orientation of the map.
3. Boundary lines of coal rights and owner identification.
4. Structure contours and dip of the coalbed being mined at not greater than 10-foot elevation intervals.
5. Location of all drill holes that penetrate the mined bed.
6. All shaft, slope, drift, and tunnel openings and auger- and strip-mined areas of the bed being mined.
7. Location of all ventilation fans.
8. Location and exact extent of adjacent active or abandoned underground workings above, below, or in the same seam. If abandoned workings are known to exist in an area, but exact extent is not known, it should be so indicated.
9. Up-to-date locations of active work areas, worked-out areas, and abandoned areas.
10. Locations of entries and aircourses with direction of airflow indicated by arrow.
11. Location of all escapeways.
12. Location and exact extent of all water pools, water-bearing strata, or fluidlike materials which tend to flow when wet (quicksands, peat, etc.).
13. Location and elevation of any body of water dammed or held back in any portion of the mine.

14. The elevation of tops and bottoms of shafts and slopes, and the floor at the entrance to drift and tunnel openings.
15. The elevation of the floors at intervals of not more than 200 feet in--

    a. At least one entry of each working section and main and cross entries.
    b. The last line of open crosscuts of each working section, and of main and cross entries, before such sections and main and cross entries are abandoned.
    c. Rooms advancing toward or adjacent to property or boundary lines or adjacent mines.

16. The owner, agent, or manager of a mine should take all reasonable steps to determine whether there is any material below the surface which could affect active, or soon to be active, areas in a mine so as to cause danger to miners working in that mine. All facts pertaining to such conditions should be presented to the manager.

Property Boundary Barrier Pillars

To insure that the mining of the coal seam by one company up to the property line does not favor that company over another company that mines later, the following guidelines are recommended.

1. A boundary pillar of unmined coal should be left to the property line; it should be of a width calculated by the equation $Pb = 10 + 2T + 5D$. Pb is the pillar width in feet, 10 is a constant safety factor, T is the thickness of the bed in feet rounded to the next highest integer, and D is the depth of the seam at the property line in 100-foot increments rounded to the next highest integer. This pillar width should be required on both sides of the property line. When mining on one side of the property line has approached closer than would be permitted by this guideline, the advancing working should increase its property boundary barrier pillar requirement so that the cumulative pillar size is equal to 2 Pb. Where faults are known to occur, which could result in a connection between the abandoned and active workings or which could seriously weaken pillar stability and strength, additional pillar widths should be used. This additional width should be based on the experience and judgment of the mine engineer and mine inspector.

2. Boundary barrier pillars should not be altered for increased mineral recovery unless the mining proposal insures inspection and certification that all of the affected workings are free from hazardous accumulations of water, and the proposal has--

    a. Been agreed to by the interested mining companies and superintendents.
    b. Been approved by the mine inspector.
    c. Received approval from the responsible government regulatory agency.
    d. Considered eventual interconnection of the mining operations by either accident or development plan.
    e. Considered the development plans from all affected mining companies.

Abandoned Workings, Abandoned Areas, and Adjacent Mines

Water-filled mine openings, the presence of which is unknown or if known the extent of which is poorly defined, are of major concern to mine operators. The following guidelines are recommended with respect to these problems.

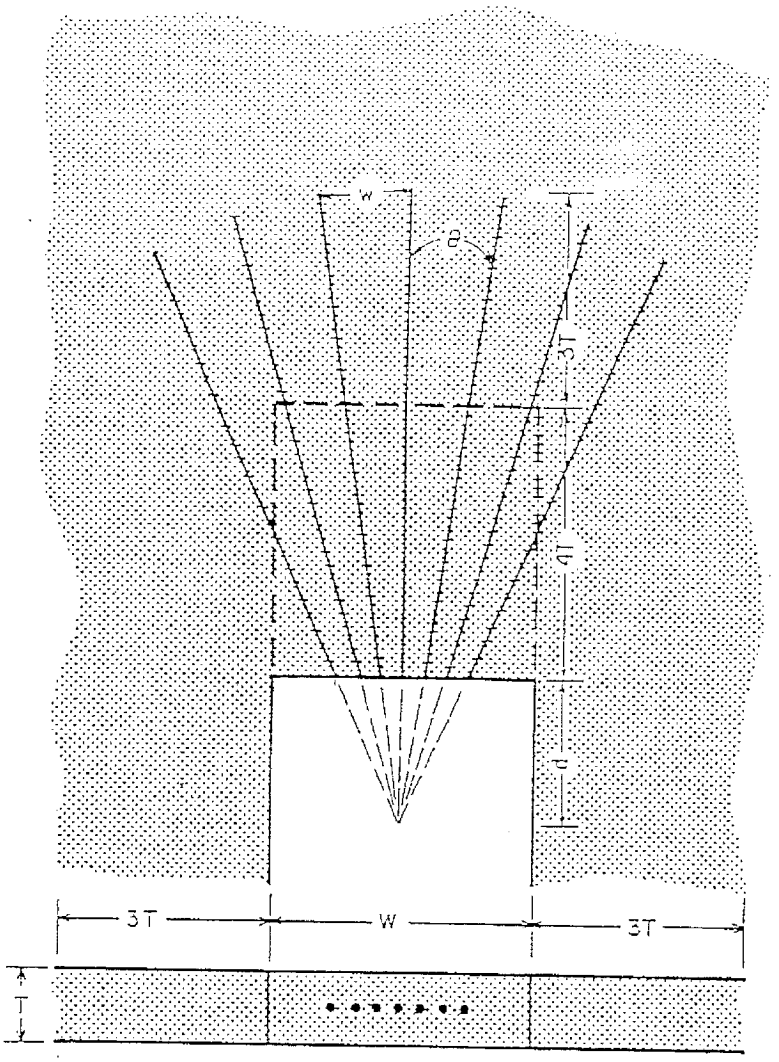
1. No mining should be permitted within 200 feet of any known or suspected abandoned workings (that are part of the present mine and/or other prior mine) which cannot be inspected and certified free of dangerous accumulations of water. When these abandoned workings can be inspected and certified as safe, mining can proceed to within the distance permitted by the Property Boundary Barrier Pillar guidelines, or to within the distance corresponding to a pillar width-to-thickness ratio of 10 to 1, whichever is larger. Where faults are known to occur that could impair the effectiveness of the pillar as a water barrier, additional pillar width may be used as determined by the mine engineer and mine inspector.

2. Locator boreholes should be drilled from the advancing face nearest to the abandoned mine through the 200-foot barrier pillar to determine the location of abandoned workings. The equipment and materials necessary to plug the borehole upon breakthrough must be available to the drill crew. The water head pressure or atmospheric conditions in the abandoned workings should be determined.

3. Unless downhole instrumentation definitely established that no water exists in the abandoned workings, even though pressure or gravity flow does not occur at breakthrough, the workings should be assumed to be flooded. If it is subsequently determined that the abandoned workings are dry, mining may proceed up to the limits of boundary barrier pillar (when approaching the property line) as defined by $Pb = 10 + 2T + 5D$; or normal mining operations should be permitted when the property limits are not a factor to be considered in this development.

4. Water may be drained from abandoned workings through a drift or auger entry, if possible, or from boreholes drilled from the surface. Water also may be drained through the 200-foot barrier pillar to the active workings and pumped to the surface. This latter method is potentially hazardous, however, and should only be used under the direction of knowledgeable and experienced personnel. If permits are necessary to discharge the water on the surface, they will need to be procured.

5. If the abandoned workings are not initially dry or drained of water, an effective safety barrier pillar should be sized by utilizing modeling techniques and unconfined compressive strength tests. For modeling, a factor of safety of 4 should be used in pillar design. Whenever the pressure head is equal to or greater than 5 atmospheres, consideration should be given to draining these workings. The permeability of the unmined barrier pillar should also be determined for consideration of its effect on waterflow and further pillar development. Two proving headings (for ventilation purposes), kept as narrow as possible and protected by boreholes, would be a safe mining plan to utilize for developing the barrier pillar up to the limits determined



Coal thickness = T
Number of holes required = $\frac{W+6T}{w}$ (next whole number)
Hole length = 7 T
Safe advance = 4T
Safety pillar = 3T
Angle θ = ATAN w/(7T+d)
w = width of old headings, if known; if w is unknown, use w = T

FIGURE 3. - Drill pattern for safe advance through coal with unknown inundation hazards.

by this recommended testing procedure. These headings should be limited to 15 feet in width. The mining crew should be alert for signs of pillar instability, excessive water leakage, strong sulfur smell, or other indicators of water, and mining halted or reevaluated as necessary. The permeability of the pillar can be reduced and its strength increased by introduction of grout or other cementing agents.

6. Whenever any working place approaches (1) within 10t or Pb, whichever is greatest, of abandoned areas in the mine as shown by surveys made and certified by a registered engineer or surveyor and the area cannot be inspected, or (2) within 200 feet of any other known abandoned areas of the mine that cannot be inspected and that may contain dangerous accumulations of water or gas, or (3) within 200 feet of known workings of an adjacent mine, a borehole configuration such as that shown in figure 3 should be drilled in advance of the working face of such working place and should be continually maintained in advance of the working face. (NOTE.--In figure 3, w is the width of the smallest old openings, if known. If not known, w is the value of the seam thickness, T).

Oil and Gas Well Pillars

Mining should not come closer to active oil and gas wells than 150 feet in any direction). When these wells are abandoned, however, they can be sealed and the barrier pillar mined through, provided that the seals are tested for leakage prior to mining.

Shaft and Vertical Opening Barrier Pillars

When these abandoned openings can be inspected and certified free of hazardous accumulations of water, they can be mined through as in normal pillar recovery operations.

When mining in the area of any abandoned shafts, raises, or other openings that cannot be inspected and certified free of dangerous accumulations of water, a barrier pillar 300 feet in diameter should be left around the opening, provided that a minimum of 100 feet of solid coal is left around the abandoned opening. Where these openings can be inspected and certified safe, a pillar of width-to-thickness ratio of 10 to 1 should be left around each opening. When mining in the area of abandoned slopes and like openings, the guidelines for mining near abandoned workings should be followed.

Mining Under Abandoned Flooded Workings

Mining under flooded abandoned workings should conform to the 60t and maximum tensile strain rules for total extraction, to the 5s or 10t rules for room-and-pillar extraction, and to the 3p or 270-foot rules for panel-and-pillar extraction.

APPENDIX

In the United Kingdom, numerous examples of total extraction beneath the sea have been examined in which no seawater passed into the mines. The maximum seabed tensile strain for each of these cases was calculated, and the results ranged from 5.0 to 15.0 millimeters per meter (mm/m). On the basis of this analysis, the National Coal Board has adopted a criterion of 10.0 mm/m of calculated maximum tensile strain as governing the minimum depth for total extraction. The expression used in the United Kingdom for calculating maximum tensile strain E_t, is

$$E_t = \frac{K\, S_{max}}{D}.$$

The value of S_{max} with longwall caving is normally taken as 0.90t, and the average value for K as 0.75 in the United Kingdom. Thus, the minimum depth of cover required for safety, D_{min} is

$$D_{min} = 67.5t,$$

where t is the thickness of the coal seam mined. For a limiting tensile strain of 5.0 mm/m, the limiting depth for total extraction would be 135t; for a limiting tensile strain of 15.0 mm/m, the limiting depth would be 45t.

If experience in the United States results in recommended strain values other than those used in the United Kingdom, these values may be used.

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