Explosion-Proof Bulkheads
Present Practices

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EXPLOSION-PROOF BULKHEADS

Present Practices

by

D. W. Mitchell

ABSTRACT

This Bureau of Mines report summarizes experience and past research on methods for sealing abandoned areas of a coal mine and areas from which the pillars have been wholly or partially extracted. The Federal Coal Mine Health and Safety Act of 1969 requires that such areas be ventilated or sealed with explosion-proof bulkheads, but the present study indicates that bulkheads alone cannot isolate areas in a coal mine in which methane and other dangerous gases have accumulated. Gas-air exchanges between sealed and open areas must be controlled.

INTRODUCTION

Areas in coal mines in which methane could accumulate must be ventilated or sealed, whichever is the more appropriate and provides the greater degree of safety (32). Sealing unused and abandoned areas was a common practice in coal mines prior to World War II (20, 23). The few seals (bulkheads) since built were principally in areas having a potential for spontaneous combustion (12).

European miners have had much experience building seals (bulkheads) for control of active fires and spontaneous combustion. Disasters, during construction and subsequently because of improper placement, led to major reappraisals by German and British commissions and then to extensive research, particularly since 1967. These are summarized in this report. A subsequent report of studies now in progress in the Bureau of Mines Experimental and Safety Research coal mines will describe methods for remote and rapid construction of bulkheads made from fly ash. Their costs and ability to withstand explosion forces, ground movements, and gas leakage will be compared with those for bulkheads made in accordance with German regulations and to the double-walled concrete block seals now being built in many coal mines in our country.

Pending completion of on-going research and development, present rules for bulkhead construction must be followed. These require that bulkheads be

1Acting research supervisor.

2Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.
constructed of solid, substantial, and incombustible materials in such a way as to prevent an explosion which may occur in the atmosphere on one side from propagating to the atmosphere on the other side (7).

RESISTANCE OF BULKHEADS TO EXPLOSION FORCES

The Federal Coal Mine Health and Safety Act of 1969 requires that bulkheads be "explosion proof." No one, however, can foretell what forces would be exerted on a bulkhead in the event of an explosion. In the Bureau's Experimental Mine, for example, propagating explosions have developed from 1 to 127 psig, and in a few trials pressure piling caused higher, unrecordable pressures, and considerable damage. Seldom, however, do pressures 200 feet and more from the origin of an explosion exceed 20 psig unless coal dust accumulations are excessive and the incombustible content of the dust is less than required by law.

Historically, "explosion proof" has been a consensus interpretation. For example, the 1921 regulation (31) for sealing connections between coal mines on U.S. Government-owned lands requires that stoppings withstand a pressure of 50 psig. This regulation was "based on the general opinion of men experienced in mine-explosion investigations" (26). Commissions in the United Kingdom following disasters in 1933 and 1960 reported that "...it is desirable in designing explosion-proof bulkheads to assume that pressures of 20 to 50 psig may develop...and that the figure of 50 psig gives a good margin of safety in practice" (17-18, 30, 36). Similarly, groups in Poland and in the Ruhr and Saar districts of Germany decided that bulkheads should withstand at least 72 psig, the upper limit of static pressure reached by an explosion of moderate strength (9, 13, 28, 34).

The first research studies on how to protect sealed areas were made in 1914 in the Bureau's Experimental Coal Mine. In these studies, rock-dust barriers on both faces of a weak stopping effectively limited propagation of flame into the sealed area even though the stoppings were destroyed (24). Subsequent studies in 1930 resulted in the concrete bulkheads described in appendix II. These bulkheads withstood 50 psig and failed at 55 psig (26) in explosion trials that developed impulses of more than 200 psi-seconds. Comparable bulkheads withstood more than 140 psig when impulses were less than 50 psi-seconds (9).

The most recent studies made were those in 1968 to develop bulkheads for mines in the United Kingdom and in the Ruhr and Saar districts of Germany. These studies resulted in the gypsum bulkheads described in appendix I, which withstood 215 psig and failed at 260 psig in explosion trials that developed impulses of up to 100 psi-seconds (13, 28).

In contrast, an 8-inch-thick bulkhead made of solid concrete blocks laid in mortar and recessed into the ribs, roof, and floor would withstand at best an explosion pressure of 5 psig (16). A 22-foot-long seal of rock and dust could be collapsed by an explosion developing 20 to 30 psig (27) as would an 18-inch-thick seal of brick laid in mortar and recessed into the ribs (24-25).
Analysis of research in this and other countries indicates that a bulkhead designed to withstand a given static load will have a considerable margin for safety should it be subjected to a greater dynamic load. For example, in present trials in the Experimental Mine, a bulkhead designed to withstand a static load of 14 psig withstood 27 explosions developing from 5 to 50 psig; 50 psig was the highest pressure developed in these trials.

Analysis indicates that an explosion pulse of high pressure and short duration would be less destructive than one in which the pressure is lower but continuously rising. High pressure of short duration could develop should the explosion involve a large body of methane. The duration might be increased and a continuously rising pressure could be developed should flame propagate into a belt entry or to where float coal overlies rock-dusted surfaces (12).

From the above it follows that a bulkhead may be considered "explosion proof" when its construction is adequate to withstand a static load of 20 psig, provided that the area to be sealed contains sufficient incombustible to abate the explosion hazard in that area and that adequate incombustible is maintained in the adjoining open passageways. Should the area to be sealed be inaccessible or unsafe to enter then rock-dust or water-trough barriers on both sides of the bulkhead would prevent propagation of a coal-dust explosion from one side to the other (25).

THE HAZARD OF GAS LEAKAGE FROM SEALED AREAS

Sealing may not protect men in active workings unless the means taken to control gas leakage are effective. In exceptional cases only can gas-air exchanges between sealed and open areas be prevented. A leakage rate as small as 100 cfm will cause an exchange of more than 1 million cubic feet of atmosphere between open and sealed areas within a week. This exchange can be with intake as well as return air courses.

Changes in barometric pressure, the flow of ventilating air through the open portion of a mine, the different atmospheres in the open and abandoned areas, massive falls of roof, and stoppage of the mine fan cause flows of gas from and of air into sealed areas. Even if seals are airtight, gases can be forced through cracks and fissures in the roof, floor, and coal pillars. Ground movements after sealing can enlarge paths through as well as around bulkheads (1, 3-6, 8, 10, 12-15, 17-18, 20-21, 30, 34-38).

Without sealing, gas-air exchanges can be expected to follow closely variations in barometric pressure. Many miners should be aware of this and should take the necessary precautions, such as testing frequently for methane and not using explosives. Flows from sealed areas, however, are not so predictable and may occur many hours after the change in pressure; by then, the danger might be forgotten. In one mine, Winter (37) found flows beginning 8 to 15 hours after the change; he found gases continuing to flow even while the barometric pressure was rising--an unlikely event were the area not sealed.

The quantity and time of flow depends on the prior barometric pressure history. For example, if a decrease in barometric pressure follows a
relatively long period during which the pressure was rising, then initial gas flows may be small. Reportedly, air may temporarily continue to flow into the sealed area. Should the decrease, however, follow a relatively long period during which the barometric pressure had been constant then initial gas flows could be large. The time when flows become dangerous also depends on conditions within the sealed area, particularly its size, leakage paths, pressure and temperature gradients, extent of caving, and on the kinds and concentrations of accumulated gases (37).

REDUCING THE GAS-LEAKAGE HAZARD

To protect men in active workings from gob-gas leakage, pressures within sealed areas must be relieved and gas-air exchanges must be controlled. Gas will flow from sealed areas toward points of lower pressure. Pressures within the sealed area must be relieved to reduce the chance that points of lower pressure are in the active workings. This can be done in part by removing gases as they accumulate. For example, in Europe, the accepted practice is to pipe gases from a sealed area into a bleeder entry or into a methane drainage system; forced exhaust may be necessary (2, 14, 21, 29, 33-38). In some mines, gases might be vented through boreholes to the surface (11). Pressure differentials between the sealed and open areas also can be controlled by pressure balancing as detailed in the literature (1, 3-6, 10, 15, 21, 35-37).

In addition, German mine inspectors examine bulkheads at least monthly and whenever the air distribution is changed. In these examinations they determine (34):

1. Condition of each bulkhead and its contact with the ground.

2. Permeability of each bulkhead (by smoke tubes or other suitable method).

3. Concentration of methane and other gases immediately outby the bulkhead and at the opened vent pipe.

4. Pressure differential across each bulkhead.

5. Air pressure outby the bulkhead (this is determined from adjacent junction points of the network).

The airtightness of a sealed area is evaluated in German mines using the following rules (37):

1. Gas-air exchanges should be suspected whenever a pressure differential exists between parallel junctions in the sealed area and in the bleeder entry. Rates of exchange should increase with increase in that differential.

2. The total of the pressure differences at corresponding inby and outby bulkheads cannot be increased by making the bulkheads more tight.

3. If leakage is suspected, it may be assumed that the greater the pressure differential the tighter the bulkhead.
4. If bulkheads are equally tight, the chance that leakage paths are through the roof, floor, or coal pillars should be suspected when the greater pressure differential is across the outby bulkheads.

5. With only one bulkhead on the outby end of a panel and more than one on the inby end, all bulkheads are equally tight when the greatest pressure differential is across the last one.

**Airtight-Bulkhead Construction**

German and British miners (29, 33-36) recommend that bulkheads be constructed in solid ground that remains unbroken. Where this is not possible, the preferred site is where ground has settled. Floor heaving, pillar crushing, and roof convergence indicate unsettled ground. The forces causing these disturbances can damage bulkheads, especially those made from rigid materials such as concrete.

Bulkheads that might be damaged by roof loads should be constructed in openings driven parallel to the face cleats, where these exist, to reduce the intensity of the shearing forces along the ribs. Where gas leakage might be a problem, advantage could be taken of roof loads by constructing bulkheads in openings driven parallel to the butt cleat.

**Bulkhead Dimensions**

A bulkhead must fill the cross-sectional area of the opening. Its thickness depends on the materials used in its construction and on the dimensions of the opening as shown by the formulas given in table 1. Those formulas incorporate two assumptions: (1) the bulkhead should resist static load of 50 psig acting in the direction of the axis of the entry and (2) future ground movements should not be excessive. The latter is of particular importance should concrete or block be used for construction. Comparable formulas to withstand a static load of 20 psig have not been developed as yet.

<table>
<thead>
<tr>
<th>Bulkhead material</th>
<th>Bulkhead thickness, feet</th>
<th>Material needed, tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete</td>
<td>0.1W</td>
<td>25</td>
</tr>
<tr>
<td>Gypsum</td>
<td>0.4W</td>
<td>46</td>
</tr>
<tr>
<td>Rock/cement grout</td>
<td>(H+W)/2</td>
<td>128</td>
</tr>
<tr>
<td>Sandbags/steel reinforcement</td>
<td>(H)W/3</td>
<td>163</td>
</tr>
<tr>
<td>Loose rock with dust or sand</td>
<td>3W</td>
<td>420</td>
</tr>
</tbody>
</table>

12.1 tons of concrete/cu yd.
21 ton of gypsum/cu yd.
31.9 tons of rock and cement/cu yd.
4Solid walls are needed at each end of the bulkhead. Each wall if made from block with mortared joints must be >14 inches thick; wood with filled joints must be >20 inches thick; bags of sand must be >40 inches thick. Wall thicknesses are in addition to that of the bulkhead (34).
51.2 tons of rock, sand, or dust/cu yd.
Bulkhead Materials

Bulkheads have been built from many kinds of material. Once, rocks, bricks, timbers, sand, dust, and cement were commonly used. Now, gypsum is preferred by British, Czechoslovakian, and German coal miners who believe it to be the most effective, easiest to use, and least costly (13-14, 21, 28-29, 33-35).

Other materials have a potential. For example, we are working with fly ash, a special bentonite, and synthetic anhydrite. All three are relatively easy to transport by pipe to the construction site. Anhydrite develops good strength; however, its strength is so dependent on the water to solids ratio (table 2) that the use of anhydrite may not be practical. Detailed information on anhydrite formulations is given by Genthe (14); construction details are the same as those in appendix I for gypsum bulkheads. Bentonite has a potential for use in filling caved areas where the atmosphere remains humid. Fly ash formulated by Bureau engineers to swell and to harden has considerable potential; bulkheads made from these formulations are being evaluated in full-scale explosions in the Bureau's Experimental Mine.

<p>| TABLE 2. - Strengths of material used for bulkheads as a function of water content (13-14, 34) |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Material</th>
<th>Water to solids ratio, gal/lb</th>
<th>Setting time, min</th>
<th>Strength, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.06</td>
<td>&gt;500</td>
<td>3,600</td>
<td>385</td>
</tr>
<tr>
<td>.09</td>
<td>-</td>
<td>-</td>
<td>330</td>
</tr>
<tr>
<td>Gypsum (German).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.06</td>
<td>30</td>
<td>500</td>
<td>180</td>
</tr>
<tr>
<td>.09</td>
<td>120</td>
<td>310</td>
<td>150</td>
</tr>
<tr>
<td>Synthetic anhydrite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.06</td>
<td>&gt;500</td>
<td>900</td>
<td>240</td>
</tr>
<tr>
<td>.09</td>
<td>-</td>
<td>290</td>
<td>100</td>
</tr>
</tbody>
</table>

British and German miners prefer not to use concrete for bulkhead construction. Concretes tend to slump and shrink and therefore cause difficulties in bonding to the mine roof. Also, the restraint needed for bulkhead integrity depends on the strength of the recesses cut into coal ribs (13-14, 26, 35).

Gypsum

British miners use "Hardstem" and "Hardstop," which are proprietary products made by heating ground gypsum under controlled conditions. These differ only in their setting times which is controlled by addition of certain chemicals during the manufacturing process; "Hardstem" sets in approximately 15 minutes whereas the two grades of "Hardstop" set in approximately 30 and 90 minutes, respectively (19, 25).
German miners use a synthetic gypsum, a low-cost byproduct from the manufacture of phosphoric acid. The time of set is controlled by the water to solids ratio (table 2) and by the amount of activator used. The activator is mainly a 1:1 to 1:8 mixture of ferrous sulfate hydrate and potassium sulfate. The mix increases slightly in bulk while setting. This is another reason gypsum is preferred over concrete, sand, rock dust, and other materials that shrink. Also, the gypsum grout penetrates fissures and cracks in surrounding rocks, which enhances the chance for obtaining a good bond to those rocks. After the gypsum hardens, it yields plastically and therefore it should be less affected by mining-induced stresses than more rigid materials such as concrete. Construction techniques are detailed in appendix I.

Sandbags and Rock-Filled Seals

Sandbags have been used to build seals for many years. These seals tend to leak air as the sand compacts. Explosion-proof sandbag seals as defined for British and German mines must have a length equal to 1/3 WH (width by height of opening) and are reinforced with steel girders across the width of roof level and at both ends (17, 35). Comparable seals in a typical U.S. coal mine would require more than 8,000 bags of sand.

Seals made of rocks, dust, and clay have been used where roof loads are considerable and squeezes are common (12). In British and German mines the length of fill must exceed 3W (width of opening) (13, 35). Comparable seals in a typical U.S. coal mine would require 300 tons of rock and dust. In addition, bulkheads made with rocks, dust, and clay or with these loose fills and cement grout are required to have solid walls at each end (4, 34-35). If bulkheads are made from block or brick with mortared joints, each wall must be >14 inches thick; if bulkheads are made from wood with filled joints, each wall must be >20 inches thick; and, if bulkheads are made from sandbags, each wall must be >40 inches thick.

Water Bulkheads

Water can form an effective and, where feasible, a low-cost bulkhead. Construction techniques are simple, requiring only that water be run or pumped into a hollow or against a dam (3). The main difficulties are water leakage and inadequate head. To withstand a static load of 20 psig, the water must be 24 feet above the roof.

CONCLUDING STATEMENT

Much remains to be learned about isolating areas in a mine in which methane and other dangerous gases have accumulated. No one can foretell what forces might be exerted on bulkheads in the event of an explosion; therefore, present studies are directed toward preventing flames from propagating into sealed areas and toward minimizing gas flows into the paths of the flame.

Materials and methods for constructing bulkheads are being reappraised. Investigations indicate that in many instances bulkheads will be built where movement of equipment and supplies could be difficult. Present studies
therefore are concerned principally with techniques that require limited preparation of the site, minimal construction of forms, and pipeline transport of materials that swell during hardening to optimize the air-tightness of the bulkhead.

Pending development of definitive specifications, bulkheads may be considered "explosion proof" when they withstand a static load of 20 psig provided that the area to be sealed contains sufficient incombustible to abate the explosion hazard in that area and adequate incombustible is maintained in the adjoining open passageways. Should the area to be sealed be inaccessible or unsafe to enter, then rock-dust or water-trough barriers, approved by the Coal Mine Safety District Manager, should be on both sides of each bulkhead. The necessity for incombustible and barriers do not apply to bulkheads in anthracite mines.

To isolate sealed areas from the active workings, pressures within sealed areas must be relieved; gas-air exchanges between sealed and open portions of a mine must be controlled; and gas leakage from sealed areas must be directed into the main return air courses, preferably through a bleeder entry. Further, sealed areas should not adjoin intake air courses. If they must, then the atmosphere in the intake air should be monitored continuously by a system that gives warning should harmful gases be detected or by other suitable means that protect the health and safety of the men in the mine. The dangers of gas leakage also can be averted by using mining plans that leave small gob areas surrounded by competent pillars.
REFERENCES


Titles enclosed in parentheses are translations from the language in which the item was published.


APPENDIX I.--GYPSUM BULKHEADS

The Bureau's Pittsburgh Mining and Safety Research Center is studying how best to build gypsum bulkheads using equipment available now in many coal mines. Procedures used in British and German mines are discussed below (29, 33-34).

Equipment and Materials

Bulkheads can be constructed by six to eight men at rates of 10 cubic yards per hour and from distances of up to 1,300 feet by using the following:

1. Sufficient gypsum, clean water, spare parts, and hoses for uninterrupted construction. Typically, 1 ton of gypsum and 140 gallons of water are required per cubic yard. The gypsum must be kept dry until used.

2. Posts (3-inch diameter), brattice, and gypsum lath for forms; three posts/100 ft² of cross-sectional area should be adequate.

3. Sampling and drain pipes with cocks and siphons.

4. Continuous mixer designed for effective wetting and uniform mixing of the gypsum and water.¹

5. A pump.¹

6. Mixer-pump hose, 1-1/2-inch minimum diameter. An elastic hose is best. It should be as short as possible to obtain a constant and smooth transfer of the grout to the pump.

7. Delivery hose, 1-1/2-inch minimum diameter. An elastic hose capable of withstanding 300 psig is best.

8. Communications between the pump and bulkhead sites.

Dimensions

The formula $T = 0.865 \sqrt{\frac{a}{50/S_f}}$ (34) can be used to determine the thickness ($T$) in feet of a bulkhead where $a$ is the width or height of opening, whichever is greater, and $S_f$ is the flexural strength of the in-place gypsum. For the flexural strength data in table 1, this formula can be simplified to $T = 0.4a$ provided $T \geq 3$ feet.

¹Not all types of mixers and pumps can be used. The National Coal Board, Great Britain, specified a MOHNO (plunger) pump type 2 or 4 NESO. It is important to remember that the plaster sets in minutes. Therefore, the powder must be fed steadily into the mixer and the grout must be pumped continuously into the forms. Batch mixing inevitably causes the plaster to harden in layers and thus weakens the bulkhead in the event of an explosion. Recirculation of the grout might block hose lines and cause layering. To avoid a weak, porous plaster, the powder and water must be mixed uniformly and thoroughly.
Preparation of Place

Site preparation need not be extensive because consolidation is affected by the grout itself. If possible, the roof should be indented and the ribs and floor should be as rough as possible to maximize frictional forces. Taking down and removing loose coal and rock is advisable but not essential. However, the site must be dry during construction; the effects of surface moisture are unknown.

Building Forms

The main purposes of the forms are to hold the grout in place and to minimize its leakage. Because gypsum sets within minutes, the forms are subjected to relatively low hydrostatic pressures. Generally, three posts hitched into the floor will provide sufficient resistance. Gypsum lath or plywood is then nailed inside the forms. Joints between the form and the mine opening should be filled; brattice cloth is adequate. Joints between the lath should be sealed or brattice should be used as a liner.

Vent and Drain Pipes

Pipes for sampling air, venting gas, draining water, and measuring pressures should be anchored in position now. They should each have a cock and water siphon; pipes and connections should be capable of withstanding >50 psig static pressure.

ONE CAUTION, with respect to pipes and to construction techniques in general, is to LEAVE NOTHING WITHIN THE FORMS THAT IS NOT RIGID AND DOES NOT SERVE A USEFUL PURPOSE.

Placing the Gypsum

Water is fed into the tank and the pump is started to insure that it functions correctly. UNDER NO CIRCUMSTANCE SHOULD WATER GET INTO THE BULKHEAD. Subsequently, the pump is stopped and gypsum and water are fed into the mixer and agitated. The powder must be poured in steadily and not allowed to fall in a mass. Care should be taken to insure that paper from the bags or other foreign matter is not allowed to enter the mixing tank.

The pump is started again and the water feed is adjusted to insure that the grout level in the mixing tank is maintained at approximately one-third. The consistency of the grout should be as thick as can be pumped. At the beginning, an excess of water is best. The quality of the grout is visually examined at the discharge end of the pump hose. The right quality is when the grout appears as smoothly flowing cream. To obtain this the water should be decreased, not the pump speed or gypsum feed. Because much time must pass before the effects of changes in water content can be observed at the discharge end, it is necessary that CHANGES IN WATER INPUT BE LOW AND CAREFUL.

The grout level in the tank can be used to insure the correct functioning of the pump. If the grout level builds up, then the grout consistency should
be thinned temporarily. Should thinning fail to restore normal pumping capacity, reversing the pump for a few seconds will usually achieve the desired effect. It is for this reason that the pump operating switch should be near the equipment.

At intervals of approximately 15 minutes, both the suction hose and delivery hose should be vigorously flexed to remove any buildup. Gypsum deposited on the hose walls can be removed by kinking the hose at the discharge end while pumping; the resulting increased pressure causes the hose to expand which should break the gypsum loose. IN THE EVENT OF ANY STOPPAGE OF MORE THAN A FEW MINUTES DURATION OR ON SHUTTING DOWN, IT IS IMPORTANT THAT ALL THE EQUIPMENT BE THOROUGHLY FLUSHED OUT WITH WATER BUT UNDER NO CIRCUMSTANCES ANYWHERE WITHIN THE FORMS.

Small leakages of grout can be controlled by holding a handful of dry plaster at the point of issue. Most large leaks can be controlled by repacking the weak spot with brattice cloth soaked in grout.
APPENDIX II.—CONCRETE BULKHEADS

Joint studies by the Bureau of Mines and the Bureau of Standards in 1930 resulted in the specifications outlined in the paragraphs that follow (26). These are applicable only to bulkheads having spans of 30 feet or less. Material requirements will average 2 tons of cement, sand, and aggregate (1:2:4 mix), 155 gallons of water, and six reinforcement rods per cubic foot of bulkhead.

Dimensions

The span (W) is the greatest distance between ribs as measured after all loose material has been removed. Bulkhead thicknesses (T) shall exceed 1 foot and be not less than 0.1W except when:

1. Height (H) is greater than the span (W), then T = H/8.
2. The coal is particularly soft or broken, then T = W/8.

Recesses shall equal T except when the coal is particularly soft or broken. In those cases they shall equal T or 2 feet, whichever is greater.

Preparation of Place

All loose coal is to be removed from the ribs for at least 3 feet on either side of the point where the bulkhead is to be placed, making the ribs as straight as possible. The floor should be cleaned for an equal distance and any loose materials must be removed. All loose roof should be taken down, and in general ribs, roof, and floor at the site selected must be as sound and solid as conditions of the strata will permit.

Cutting the Recesses

The recesses in the ribs should be marked off according to the dimensions determined by the span of the bulkhead and care must be taken to avoid shattering the coal on the sides of recesses. The outer corners must be left as square as possible; the inner corners should be cut back square.

Preparation of Roof and Floor

A trench is to be made in the floor between the two recesses. It should be as wide as the recesses and extend into them. The trench must be at least 12 inches deep and extend through all loose material. Holes shall be drilled to a depth of 18 inches along the center line at intervals of not more than 18 inches. Steel rods, at least seven-eighths of an inch in diameter and 38 inches in length, are to be grouted into them.

It is not advisable to cut a trench in the roof, both because it makes planes for shearing along which the roof material may break and because the space cut in the roof cannot be properly filled with concrete. For tying the bulkhead to the roof, holes 1-1/8 inches or larger in size should be drilled.
in the roof along the center line of the stopping at intervals of not more than 18 inches; the holes should be at least 18 inches deep. Reinforcement rods at least seven-eighths of an inch in diameter and 30 inches in length are to be driven into stiff grout into these holes.

Building the Form

The form should be constructed tightly of good lumber, properly braced, and tied to prevent movement while the concrete is placed and is setting. The ends of the forms are to be flush with the edges of the recesses and should not extend into them. On the near side, the studding, braces, and ties should be completed and the form boards should be placed to about half height. The remainder of the boards should be cut and placed so that they are readily available for insertion as needed.

Mixing the Concrete

The concrete should not be leaner than 1 part cement, 2 parts clean sand, and 4 parts clean gravel or broken stone (1:2:4) by volume. It should be mixed thoroughly so as to be homogeneous and so that all material will be wet properly; only enough water should be used to give the stiffest consistency that can be properly spaded in the form. Overwatering must be avoided, as it reduces the strength of the concrete.

Placing the Concrete

Water in the floor trench should be removed before concrete is placed. The concrete should be well spaded, as it is placed in the form, by edged wooden paddles or other convenient device. Care must be taken to fill the recesses completely. The concrete is placed in successive horizontal layers from one buttress to the other. THERE MUST BE NO PAUSE GREATER THAN ONE-HALF HOUR IN MIXING AND PLACING THE CONCRETE FOR THE ENTIRE STOPPING. HOWEVER, IF THERE IS AN UNAVOIDABLE DELAY, AT LEAST 7/8-INCH-DIAMETER AND 16-INCH-LONG REINFORCEMENT RODS SHOULD BE SET VERTICALLY IN THE LAST LAYER ABOUT 18 INCHES APART AND PROJECTING UPWARD 8 INCHES OR MORE.

As the roof is approached, spading becomes more difficult, but it must not be neglected. The concrete should be well worked around the iron rods projecting from the roof. The final form board on the side from which the concrete is placed should be set in short sections, beginning at the ribs, and the concrete should be rammed back into the space so that it is tight against the roof. The final portion at the center should be not more than 2 feet wide, and as much stiff concrete as possible should be placed in this space.

Finishing the Stopping

The form should not be removed for at least 4 days after the concrete has been placed. Not later than 7 days after the concrete has been placed, the top boards and framing on the side from which the concrete is placed should be removed and any voids at the roof should be filled by ramming and plastering. This work should be done with a cement gun if available.