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Bureau of Mines Report of Investigations/1985

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By R. L. Soderberg and R. A. Busch



UNITED STATES DEPARTMENT OF THE INTERIOR



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UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
Robert C. Horton, Director

Library of Congress Cataloging in Publication Data:

Soderberg, R. L.

Bulkheads and drains for high sandfill stopes.

(Report of investigations / United States Department of the Interior,
Bureau of Mines ; 8959)

Supt. of Docs. no.: I 28,23:8959.

1. Mine filling. 2. Mine drainage. 3. Stopping (Mining)—Safety measures. 4. Rock bursts. I. Busch, R. A. (Richard A.). II. Title. III. Series: Report of investigations (United States. Bureau of Mines) ; 8959.

TN23.U43 [TN292] 622s [622'.8] 85-6000 14

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm/s	centimeter per second	in/h	inch per hour
ft	foot	m	meter
ft ³ /min	cubic foot per minute	mm	millimeter
ft ³ /s	cubic foot per second	pct	percent
gal/min	gallon per minute	psi	pound per square inch
in-diam	inch-diameter	yr	year

BULKHEADS AND DRAINS FOR HIGH SANDFILL STOPEs

By R. L. Soderberg¹ and R. A. Busch²

ABSTRACT

Large open stopes mined by vertical crater retreat or sublevel stoping are sometimes backfilled with uncemented sand tailings to support the stope walls and alleviate rock bursts. The failure of bulkheads in two different mines prompted a research project at the Bureau of Mines to prevent a recurrence of these failures. A series of laboratory tests with gravel drains and sand filters was conducted to measure the bulkhead pressures when adequate drainage was maintained. Results showed that bulkhead pressure was reduced to near zero while drains were in operation, as compared to full hydrostatic pressure when drains were blocked or drainage was restricted. A relatively simple, light, free-draining bulkhead was shown to be adequate.

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INTRODUCTION

The use of mill sand tailings for filling large underground open stopes has been common for nearly 40 yr. With the advent of long-hole ring drilling from sublevels or vertical crater retreat mining, these stopes may be as large as 300 to 1,000 ft long, 50 to 150 ft wide, and 300 ft high.

To mine the pillars left when these bulk mining methods are used, or to provide ground control, these stopes must be backfilled. Mill tailings are the most common materials available at a reasonable cost.

Two examples of bulkhead disasters are cited below. The information was obtained by personal communication with the various mines; no reports or publications are available.

In the midforties, the Chelan Division of Howe Sound Co. began using this method of backfilling by building a reinforced concrete bulkhead in a raise below the stope. This bulkhead was constructed without drains and designed with hitches in the walls to form a tapered solid plug to withstand the full hydrostatic pressure. The plan was to decant the water off the top of the fill. To accomplish this, percussion holes were drilled at 10-ft vertical intervals from the pillar raise into the stope. The clear water was decanted from each hole until the sand reached that level. The hole was then blocked with a wood plug, and the water was allowed to rise to the next hole. A rock burst occurred in the area which may have affected the integrity of the bulkhead. Eventually, the hydrostatic head became great enough to crack the bulkhead. The sand was under such pressure that it immediately eroded a

large hole and flowed into the mine workings. All the personnel were safely evacuated, but it took several months to clear the levels and the shaft.

Recently, the Hudson Bay Mining and Smelting Co. Mine at Flin Flon, Manitoba, had a bulkhead failure that flooded several levels and the shaft and caused the loss of one miner. A wood bulkhead had been carefully designed and constructed. Every precaution was taken to prevent trouble. Wood box drains with burlap filters were placed in front of the bulkheads, with pipes through the bulkhead to prevent high hydrostatic pressure build-up. Pressure gauges placed in the bulkheads registered no pressure and were later removed. Excess water was pumped off the top of the fill after each pour, and total water into and out of the mine was carefully monitored. Several wood, mousetrap drains collapsed, the hydrostatic head built up rapidly, and the bulkhead failed, flooding the mine.

A mine in Tennessee used 4-ft-thick concrete bulkheads with No. 6 reinforcing steel at 4-in centers, but had no drains to remove the water. Leaks through the rock and around the bulkheads caused the operator to abandon the method and substitute loose rock backfill in the stope. This fill was obtained from the surface and dropped through a borehole. To the investigator's knowledge, there have been no massive failures.

This Bureau of Mines research project involves the testing of model stopes with bulkheads in the laboratory utilizing tailings fill and various combinations of filter materials. The report will indicate the equipment and procedures used and the test results obtained.

ACKNOWLEDGMENTS

The authors are grateful to the management of Hudson Bay Mining and Smelting Co. of Flin Flon, Manitoba, for permission to reference their problem in this report. Special thanks go to Spokane

Research Center personnel--Doug Piper, machinist, Mike Jones, engineering technician, and Roger McVey, supervisory electronics technician--for equipment fabrication and instrumentation.

RESEARCH PLAN

The problem with high stope backfills is the excess hydrostatic pressure that can develop because of inadequate drainage. The downstream toe of earth dams and of some tailings dams employs blanket drains designed to discharge seepage water and effectively reduce the neutral stress in the dams. The same concept can be adapted to stope backfilling. The plan would include installation of perforated steel pipes covered with coarse gravel and protective filter combined

with a relatively light bulkhead in the crosscut near the drawpoint. A drain of this type would be positive, could be designed to remove all the water draining from the stope, and would be economical to construct. It would discharge clean water free of sand and would place little or no pressure on the bulkhead because the water pressure is reduced to atmospheric in the drain. Because the plan showed definite promise, a research project was designed to test the concept.

RESEARCH EQUIPMENT

During the initial research on the bulkhead and drains, a 4-in-diam plastic pipe, 14 ft long, was placed upright against the laboratory wall to simulate the stope. A 4-in-diam plexiglass pipe, 12 in long, was attached to the bottom so it could be easily detached from the plastic pipe. A 2-1/8-in-diam plexiglass pipe, 4 in long, was cemented to the side of the larger plexiglass pipe perpendicular to its axis to simulate a crosscut to the drawpoint (figs. 1-2). The use of plexiglass for the bottom sections

enabled observation of the water exiting the fill.

A bulkhead sealed with an O-ring and containing a 25-psi pressure cell was used to measure the drained filter pressures below 3 psi. A second bulkhead with a 100-psi cell was used for the high-pressure tests. Two pressure gauges were installed on the vertical pipe used to simulate the stope, one at 10 in above the drainage material and the other 36 in higher on the pipe. These gauges acted as checks on the pressure cell.

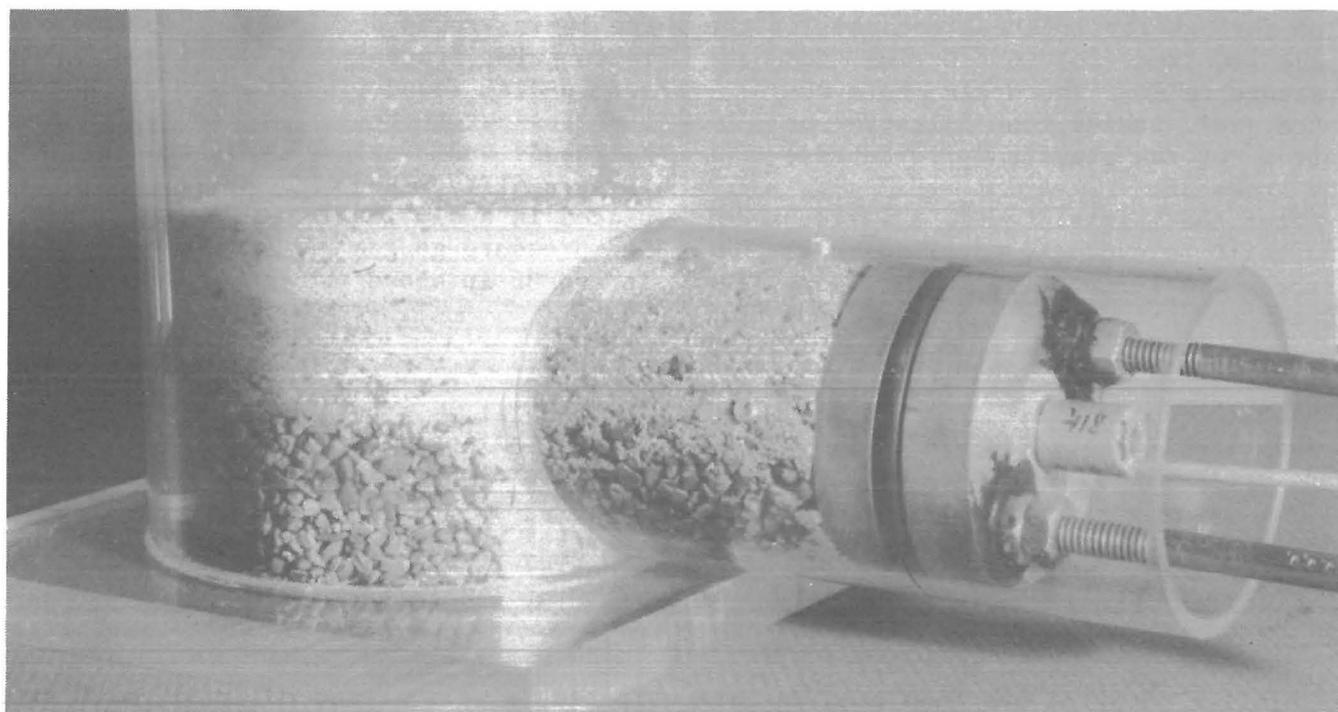


FIGURE 1. - Plexiglass model showing gravel drain, sand filter, bulkhead, and pressure cell.

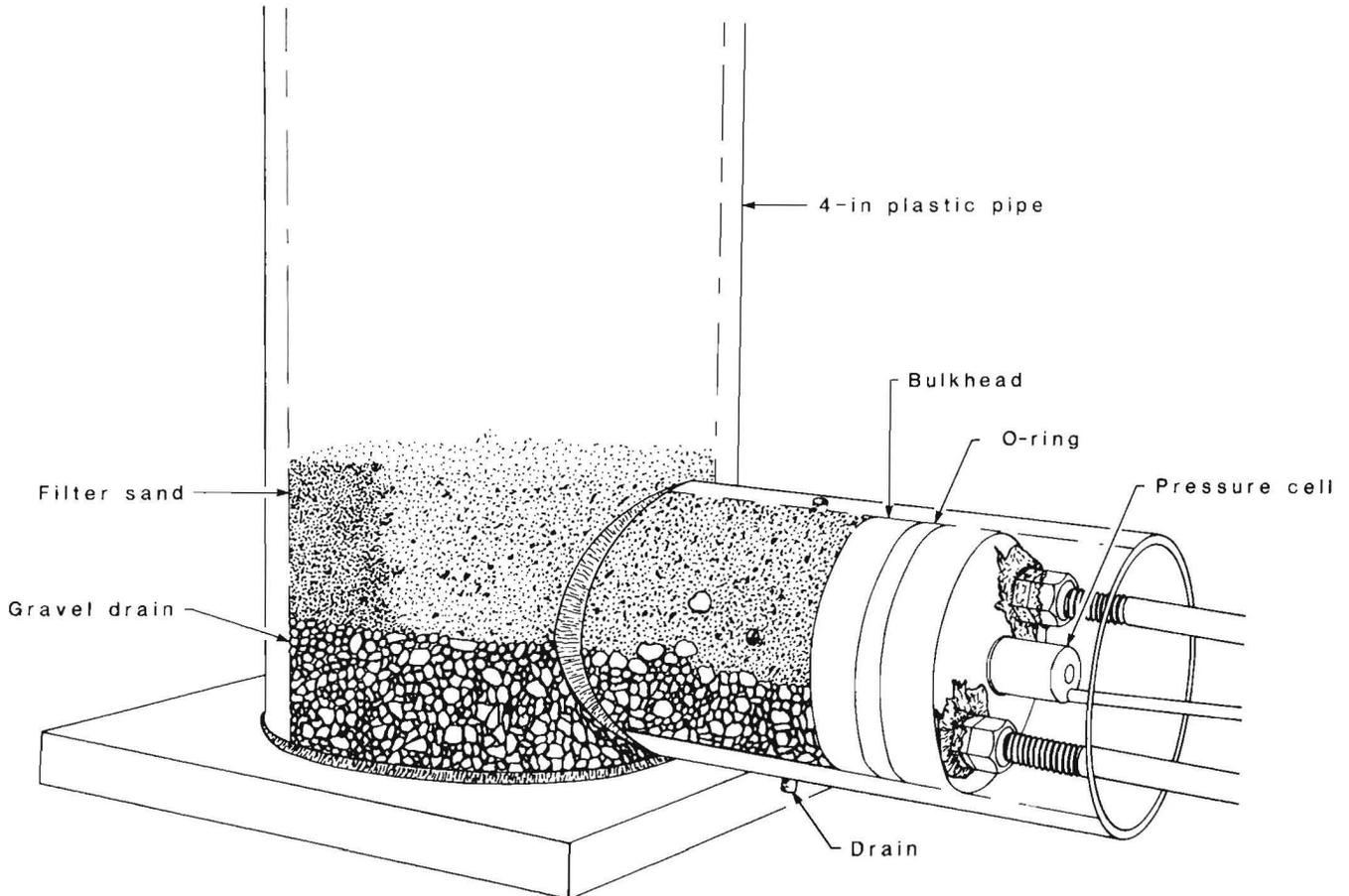


FIGURE 2. - Original laboratory model.

It was impractical to place a drain pipe through the bulkhead because of the space required for the O-ring and the pressure cell. The drain hole was located just inside the bulkhead on the bottom of the plastic pipe representing the crosscut.

After the initial tests, a larger model was built to evaluate possible scale-down errors. A 14-in pipe, 15 ft long, replaced the 4-in pipe. Again, a removable

bottom section was made that tapered from the 14-in round section to a 2-1/8-in rectangular drawpoint at a 40° angle into a 2-in-diam round pipe, which represents the crosscut to the drawpoint. The same bulkheads and pressure cells were used on this facility, and the drain hole was placed in a similar location (figs. 3-4). The pressure gauges were again placed 10 in and 36 in above the filter (fig. 5).

TAILINGS TEST MATERIAL

The backfill material used in this test was unclassified tailings from a lead-silver mine where the principal gangue mineral was quartz with 40 pct smaller than 200 mesh. This fine, sandy, silty material is granular with a total absence of clay. The percolation rate was 4 in/h, which was deemed to be satisfactory as similar material has been used in cut-and-fill stoping for years.

The tailings used in most of these tests were not formerly considered ideal for stope fill as they contained more material passing 200 mesh than was previously deemed desirable, but as the material was siliceous with angular particles, the percolation rate was satisfactory. If no cement additive is anticipated, a well-graded material with some fines (not clay minerals) makes a dense



FIGURE 3. - Test facility—14-in pipe, 15 ft long.

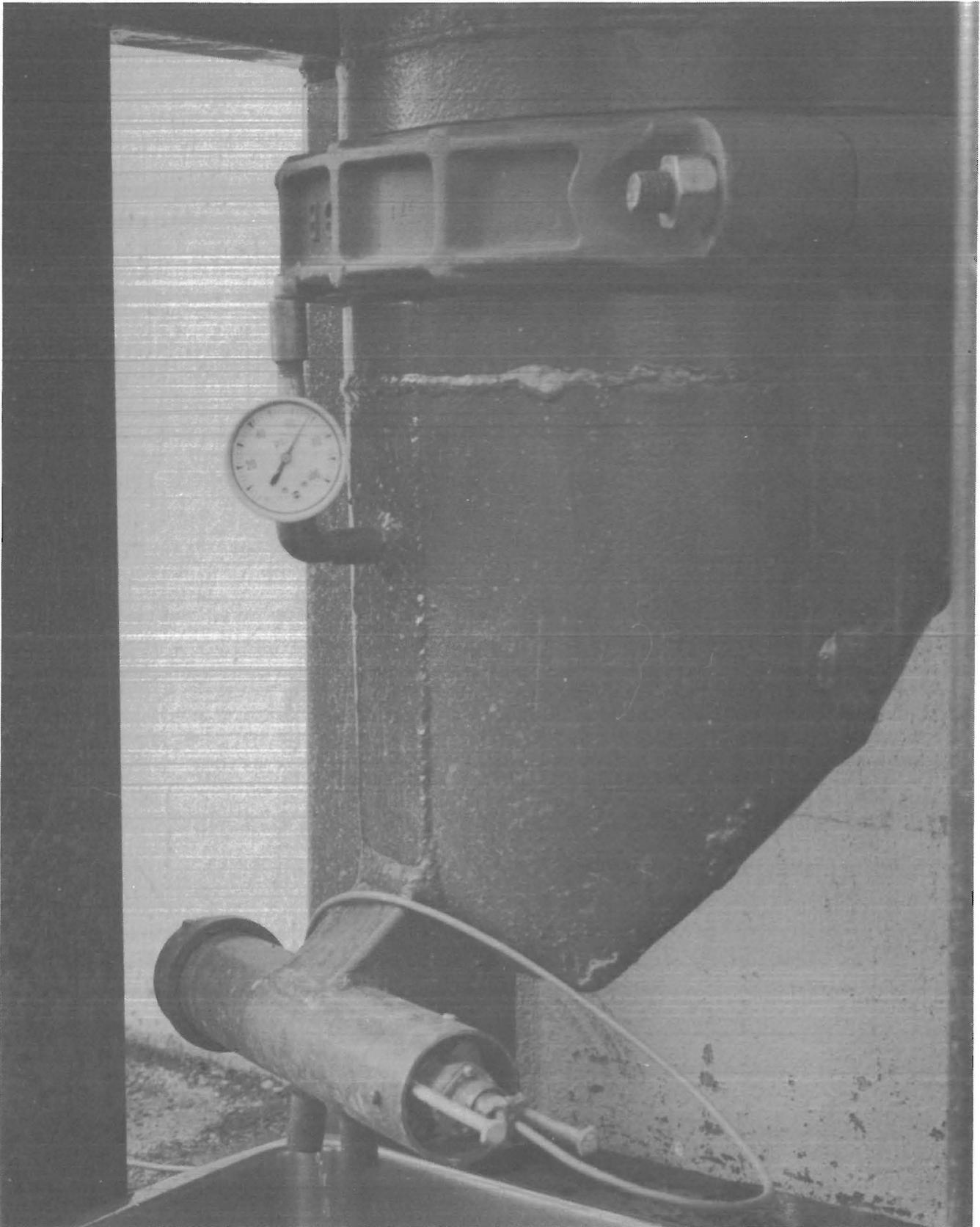


FIGURE 4. - Test facility—simulated stope bottom with drawpoint and crosscut with pressure cell in the bulkhead.

fill and is actually better than a coarser sand. The gradation of the total tailings, as used, is shown in figure 5. The results of one test with this tailings material, over a 16-day period, are shown in figures 5 and 6. Note that the bulkhead pressure scale has been de-

creased 10 times in order to show it on the same figure as the applied pressure.

The drain material is subrounded gravel, 2 to 4 mm in diameter. The filter is a quartz sand, grading from 0.6 mm to 0.09 mm, and conforms to proper filter criteria.

FILTER AND TRANSITION ZONES

A protective filter is any porous material that has openings small enough to prevent movement of soil into the drain and yet is more pervious than the soil it is protecting. Transition zones are also filters between a very fine and very coarse material where several different filter materials have to be used. Several of these transition zones or filter layers may be required, depending on the difference in grain size between the tailings and the drain materials.

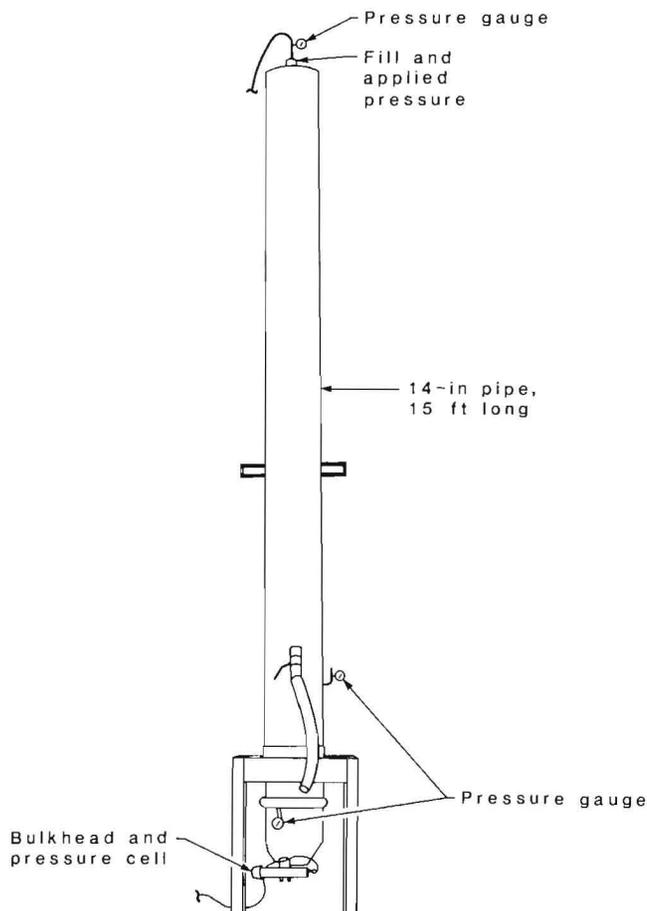


FIGURE 5. - Test facility—showing gauge arrangement.

To satisfy the criteria for filter materials, the following rules³ should be applied:

1. The 15-pct size of the filter divided by the 85-pct size of the protected soil should be less than 5.

2. The 50-pct size of the filter divided by the 50-pct size of the protected soil should be less than 25.

3. The filter material should be smoothly graded; gap-graded materials should be avoided.

4. The 15-pct size of the filter divided by the 15-pct size of the protected soil should be greater than 5.

5. The filter should not contain more than 5 pct of particles, by weight, finer than the No. 200 sieve, and fines should be cohesionless.

6. The coefficient of uniformity of the filter should be between 5 and 20 to prevent segregation during placement.

Filters need not screen out all the particles of the tailings, only the coarsest 15 pct, or the D_{85} size. These coarser particles (D_{85} and larger) will collect over the filter openings and screen out the smaller particles. If soils are used as filters (such as transition zone and cobbles), the effective diameter of soil voids must be less than D_{85} of the soil being filtered. Since effective pore diameter is about one-fifth of the D_{15} size, the D_{15} of the filter should be less than the D_{85} of the soil. The filter must provide free drainage. Because the permeability coefficient varies as the square of the grain size, the ratio of permeabilities of over 20 to 1 can be secured by making the D_{15} of the filter greater than five times the D_{15} of the soil.

³Cedergren, H. R. Seepage, Drainage and Flow Nets. Wiley, 1967, 467 pp.

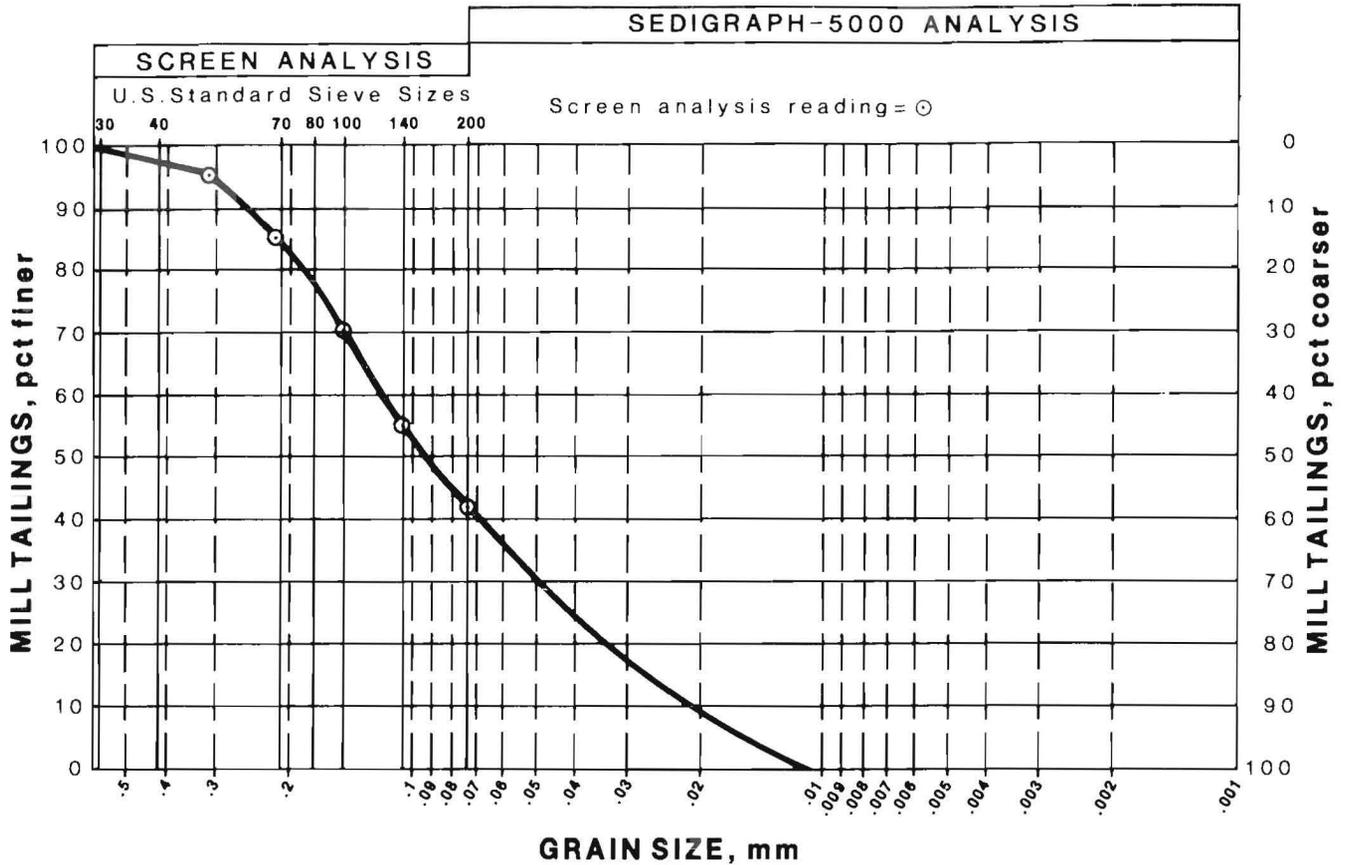


FIGURE 6. - Unclassified mill tailings used in most tests.

TEST PROCEDURES AND RESULTS

The first step in setting up each test was to secure the bulkhead in the pipe simulating the crosscut at the proper distance from the drawpoint. The gravel blanket drain was placed on the bottom of the crosscut. The depth ranged in the series of tests from one-quarter to one-half the crosscut height. The sand filter was placed on top of the gravel drain and extended up into the drawpoint. This filter material satisfied the criteria as previously outlined and was designed to prevent the tailings from penetrating the gravel drain. The tailings, at 60 pct solids by weight, were pumped into the top of the pipe (fig. 3).

When the drain was left open while placing the tailings, and when the pipe was full, the pressure cell in the bulkhead showed a pressure of 0.3 psi, the pressure gauge 10 in above the crosscut showed 1.0 psi, and the gauge 36 in

higher in the column indicated 0.7 psi. These low readings indicate the dynamic fluid pressures under drained conditions with no induced pressure, which are practically negligible. The bulkhead pressure is the lowest because it is downstream from the drain.

When the drain was closed during the filling of the stope, all gauges registered a pressure proportional to the height and the density of backfill slurry in place. To apply greater pressure on the backfill, simulating greater heights of fill, the pipe was capped and air or water pressure was applied. Pressure was applied in increments, and readings were taken on the pressure cell and the pressure gauges. As long as the sand was saturated, the pressure increases were relative at all measuring points (table 1). The maximum test pressure was 100 psi (figs. 7-8).

increased to a maximum of 1.5 psi. The pressure applied at the top of the column has very little effect on the pressure registered against the bulkhead as long as the drains are open. The highest ever recorded was 1.5 psi when the applied pressure was 100 psi; normally, the variation is only 0.3 psi either way. In actual operations in a mine, the drains would never be closed. They were closed in this test facility only to check the functioning of the load cell by comparing pressures with the two dial gauges. As long as the drains were designed properly with sufficient cross-sectional area so that their capacity was much greater than the flow from the stope, there was little pressure against the bulkhead (figs. 7-8). A drain such as this, composed of hard, chemically resistant rock, is much better than filter cloth because there is no deterioration or loss of filter capacity with time.

RESEARCH APPLICATION TO MINE FILL OPERATIONS

The results of this research can be applied directly to any stope-filling operations where mill tailings, or surface sand with or without cement, are used and placed as a high-density slurry. In this situation, a large portion of the excess water can be decanted off, but the main problem is to control the water that seeps through the fill. Unless adequate drains are provided, this can cause high hydrostatic pressures against the retaining bulkhead.

A conceptual design, applying this research to an underground mine fill, is presented. Since the characteristics of each mine vary, the actual design must be based upon site conditions. The following steps or procedures may apply.

To prepare a stope for fill, a few simple steps should be followed. The drawpoint should be thoroughly cleaned up to where the cone starts, even to the

TABLE 2. - Gauge pressures with bottom drain open, pounds per square inch

Date	Induced water pressure	Gauge 1	Gauge 2	Bulkhead pressure cell
5/24	59	62	63	0.14
5/25	35	40	41	.13
5/26	60	66	68	.16
5/27	60	63	66	.05
5/28	60	65	66	.02
6/1	60	66	68	.21
6/2	58	65	68	.12
6/3	58	65	69	.05

NOTE.--Gauge 1 was 11 ft below the top of the 14-in pipe. Gauge 2 was 14 ft below the top of the 14-in pipe. The water pressure was applied continuously, and the pressure readings reflect the dynamic head.

extent of washing it somewhat to remove material that might wash down when the first slurry is placed in the stope. Some of this material may be detrimental to the filter. The easiest way to place the filter sand may be from above, and care should be exercised to prevent contamination by material in the stope.

The crosscut leading to the drawpoint should also be cleaned to a smooth level floor, but not necessarily removing all the accumulated fine material. The bulkhead should be placed at a minimum distance of 1-1/2 times the crosscut height outside the brow of the drawpoint. Hitches should be cut into both ribs and the floor of the crosscut to anchor the bulkhead. A hitch in the back of the crosscut is optional. The perforated pipes, gravel drain, filters, bulkhead, and decant pipes should then be installed in preparation for filling (fig. 9).

DRAINAGE CALCULATIONS

To design the drain required, the anticipated flow must be calculated. The grain size of the tailings to be used as fill will determine the grain size of the

finest filter sand necessary between the tailings and the gravel drain. The permeability (k) of this filter sand must then be determined by laboratory tests.

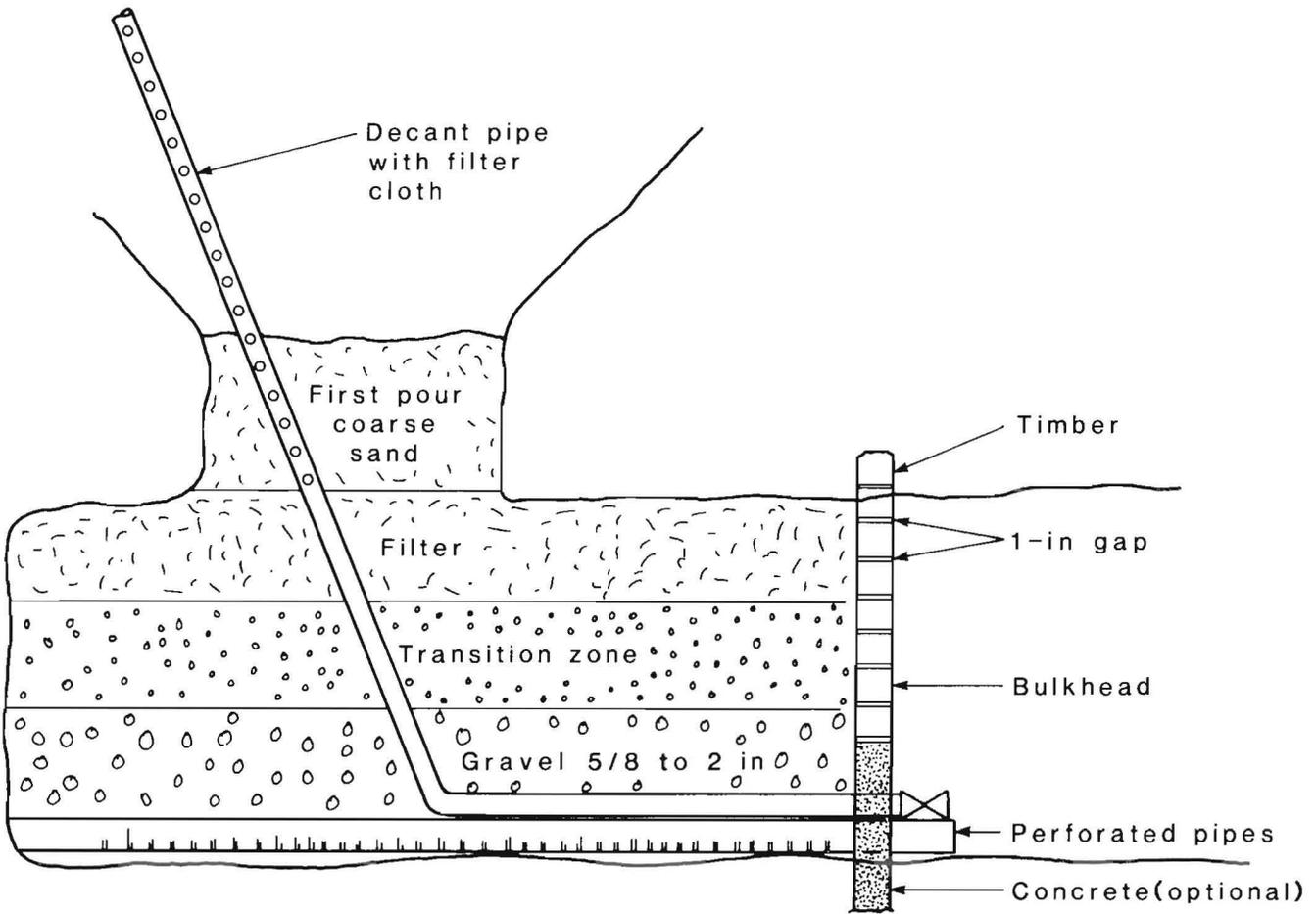


FIGURE 9. - Cross section through drawpoint with perforated pipe, drain, filters, and decant pipe.

For example, assuming the worst situation possible (most conservative), that the filter will pass the maximum water with the maximum head, calculate the total flow entering the filter from the Darcy formula:

$$Q = kIA, \quad (1)$$

where Q = quantity of water in gal/min,

k = permeability in cm/s,

I = hydraulic gradient $\Delta h/L$ (assume 1.0),

and A = cross-sectional area of final sand drain.

Calculations: Assume: $K = 5 \times 10^{-2}$ cm/s,

$I = 1.0,$

and $A = 100$ ft²,

$$Q = 0.05 \times 1.9685 \times 1.0 \times 100,$$

$$Q = 9.84 \text{ ft}^3/\text{min},$$

and $Q = 73.6$ gal/min.

Note: To convert cm/s to ft/min, multiply by 1.9685.

If a factor of safety of 10 is desired, the design would be for a flow of 100 ft³/min or 1.67 ft³/s. This would require three 6-in or two 8-in pipes in the drain.

DRAIN PIPES

Filter criteria state that the holes in the drain pipe should be smaller than the

D_{85} size of the material it is draining. Where coarse gravel is used to surround

the perforated pipe, this criterion does not apply. When perforated pipe is not available, slots may be cut into 6- or 8-in pipe, but the slots should be no more than 1/2 in wide, assuming the gravel size is +5/8 in. Only the bottom one-quarter of the pipe is to be perforated, with the slots at right angles to the pipe and spaced at 3-in centers along

that portion of the pipe in the area to be drained. Slots may be cut parallel to the pipe axis, providing the same area of openings. It is important that a surplus of slots be cut to ensure that the water can flow freely into the pipe. The cross-sectional area of the slots should be three to four times the cross-sectional area of the pipe.

GRAVEL DRAIN

The coarse drain material can be either rounded river gravel or crushed rock and should be well graded from 5/8- to 2-in size. A siliceous rock is preferable, and mandatory if the water is acidic, so there is no chemical reaction to deteriorate the material. It should also have a high strength to resist crushing. A good

hard limestone is acceptable if acid water is not a problem.

A bed of gravel 6 in thick should be spread on the floor of the crosscut beneath the drain pipes and extend above the pipes to a total depth of gravel of about 3 ft; this gravel can be placed with a front-end loader.

FILTERS

On top of the coarse gravel, several layers of filter material, each decreasing in size and conforming to the filter criteria, will be necessary to prevent the tailings from washing into the gravel, but yet allow a free flow of water.

These transition zone filter layers can also be placed with a front-end loader. Some handwork would probably be necessary to spread and level the material.

The final filter sand would have to be placed pneumatically through the bulkhead, or hydraulically through the fill pipes, whichever is most convenient. If pneumatically placed, the sand will be very loose. This must be taken into consideration when depositing the filter so that when it becomes saturated and compacted, there will be ample sand to fill the area. The first pour into the stope should be the same filter sand and extend at least 3 ft above the brow of the draw hole. This is a precaution to ensure complete filling of the crosscut and a

portion of the draw hole prior to tailings deposition (fig. 9). These filters must conform to filter criteria and be designed to allow water to flow freely from the tailings in the stope fill through the filter and transition zone into the gravel and drain pipe without carrying fines or clogging the filter. After the initial fill, the water will wash all the dirt and fine sand from the sand and gravel drain material. After this, there should be only clean water exiting the drain. The permeability value for each material from the tailings to the gravel should be increased by a factor of 10 or more. The grain size of the filter is governed by the grain size of the tailings used for fill. Successive filter layers make the transition to the gravel surrounding the drain pipes. Specifications for choosing the proper filter gradation are outlined in the "Filter and Transition Zone," section of this report.

BULKHEAD

The bulkhead should be constructed of reinforced concrete, hitched into the walls and floor, and high enough to extend 2 ft above the top of the drain pipes. This will direct all the water to

the pipes, where it can be disposed of as desired. Above the concrete, square timbers are laid horizontally and supported by vertical posts. Since this portion of the bulkhead should *not* be watertight,

these timbers should have a gap that will restrain the gravel but allow the free flow of water. If the drain is designed properly and performs as planned, the water should never get above the top of

the concrete. To keep the transition and filter sand from going through the bulkhead, the gravel should be placed against the bulkhead up to the top of the cross-cut (fig. 9).

DECANT

The clear water from the top of a stope fill may be pumped off after the fines have settled. However, this is probably the most unsatisfactory way to remove the water because it requires access to the stope and personnel to place and operate the pumps. There also exists the probability of pumping dirty water.

The vertical crater retreat method of ore breaking does not require a raise in the pillar beside the stope being filled. However, if a raise is available, horizontal holes of any convenient diameter from 2 to 4 in can be drilled from the raise into the end of the stope for decanting the water. The spacing between holes would be optional (fig. 10).

A preferred method of removing the water from the top of the fill is to install several decant pipes from the draw-point up to an access drift in the pillar (fig. 11). The size of the pipes depends on the size of the stope and the filling rate. These pipes should have holes

spaced at 6-in centers from the top down to the sand filter. Below the filter and out through the bulkhead, the pipes should be solid. Outside the bulkhead, a valve should be installed as a precaution in case the pipe is broken by falling rock. The valve could then be closed to prevent tailings from being discharged. The decant pipe should be covered with a filter cloth to prevent any of the fine sand from entering it. A variety of filter cloths should be tested to determine which would best prevent the infiltration of fines into the decant pipe. Using a decant pipe to remove the water from the top of the fill presents several advantages. There would never be a large depth of water in the stope at any time, water removal starts as soon as filling starts, water clarification is not necessary before removal, no work force is required, and filling can be continuous if desired.

CONCLUSIONS AND RECOMMENDATIONS

This research project demonstrated the importance of filter layers and drains to relieve the pressure on a bulkhead that is designed to retain an unconsolidated sandfill. The reduced pressure on the bulkhead when the drains were operating increased the integrity of the bulkhead and the safety of the simulated mine.

It is recommended that mines filling large stopes with mill tailings consider using the blanket drains and bulkhead concept as outlined in this report. Attempts to permanently seal these high stopes with reinforced concrete are extremely dangerous, and the practice should be stopped. Traditionally, the criterion for sandfill was to have a percolation rate of 3 to 4 in/h. This would be a relatively clean sand with a small amount of fines to act as a binder. Without sulfides that oxidize and act as a cementing action, or compaction from

squeezing ground, clean sand may have a tendency to run. By leaving more of the

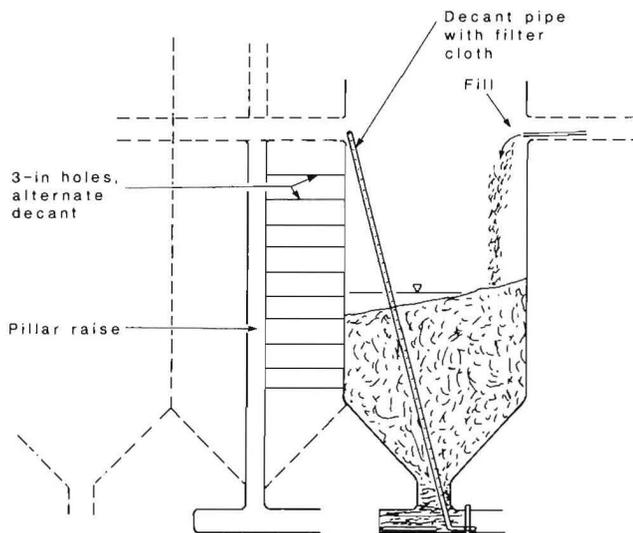


FIGURE 10. - Stope elevation—alternate decants.

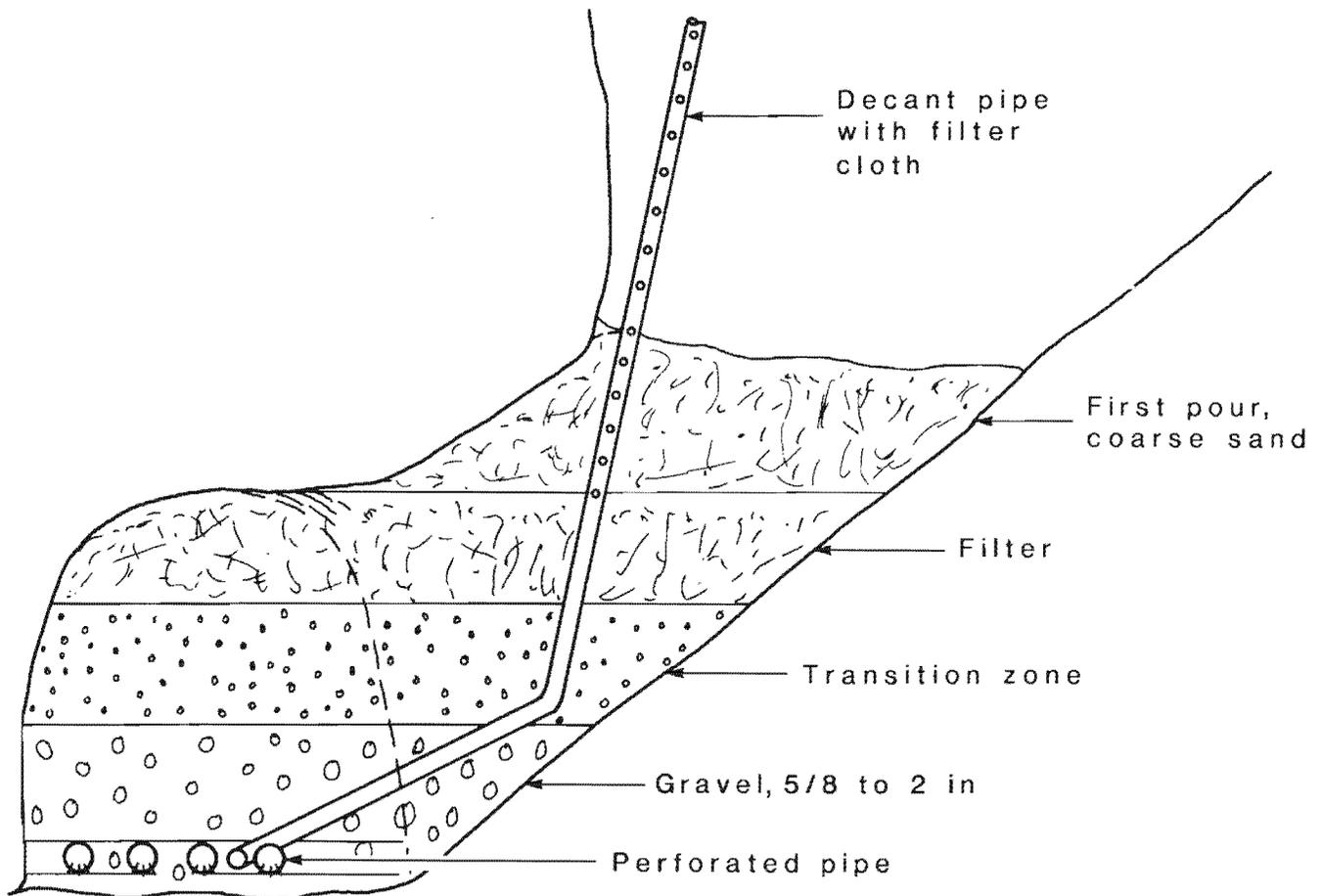


FIGURE 11. - Longitudinal section with perforated pipe, drain, filters, and decant pipes.

fines in the sand, the fill will have a higher density and offer more support, as well as greater strength, and could be freestanding when exposed. In a few cases, it may be possible to use unclassified tailings directly from the mill, reducing the percolation rate by as much as one-third; but even in these situations, the tailings should be free-draining and void of clay particles.

It is not anticipated that a strong bulkhead would be required, considering the pressures indicated in figures 5 and 6, which are under 1.4 psi. However, extreme care should be exercised in

planning the drainage. The gaps between the timbers are extremely important. Should water ever overtop the concrete and flow through the gaps, it would be a warning that the drain is inadequate, and the fill rate should be reduced. Proper design and installation of the blanket drain and bulkhead concept should prevent this from happening.

The data from this research project have indicated the importance of using blanket drains and open bulkheads for retaining the backfill in a safe manner in large open stopes.