Modern Hydraulic Filling in Underground Metal Mines

Rainer Gevers

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Report on
MODERN HYDRAULIC FILLING
IN UNDERGROUND METAL MINES

Submitted to
Professor Koehler S. Stout
Assistant Professor of Mining

For
Mining 68
Montana School of Mines

By
Rainer Gevers

Butte, Montana
May 11, 1956
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>INTRODUCTION</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes of Hydraulic Fills.</td>
<td>8</td>
</tr>
<tr>
<td>Applications of Hydraulic Filling</td>
<td>13</td>
</tr>
<tr>
<td>Techniques Employed</td>
<td>15</td>
</tr>
<tr>
<td>Mining Methods</td>
<td>19a</td>
</tr>
<tr>
<td>Costs</td>
<td>20</td>
</tr>
<tr>
<td>Conclusions</td>
<td>21</td>
</tr>
<tr>
<td>Bibliography</td>
<td>22</td>
</tr>
</tbody>
</table>

# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 A Closed-Pipe, Gravity System</td>
<td>17a</td>
</tr>
<tr>
<td>2 Stoping Cycle, Cut-and-Fill Stop</td>
<td>19a</td>
</tr>
<tr>
<td>3 Stoping Cycle, Open Stop</td>
<td>19a</td>
</tr>
</tbody>
</table>
May 11, 1956

Professor Koehler S. Stout  
Department of Mining Engineering  
Montana School of Mines  
Butte, Montana

Dear Mr. Stout:

In accordance with your instructions at the beginning of the semester, I submit the following report on Modern Hydraulic Filling in Underground Metal Mines.

The entire report was written from printed sources in the school library. It was necessary to qualify the subject by the word "modern", because hydraulic filling has been practiced for a considerable length of time, and today we are mainly interested in modern principles and techniques which supersede the earlier ones. For this reason, all material that was published before 1930 was deleted.

Sincerely,

R. Gevers

R. Gevers
INTRODUCTION

While the practice of back-filling is almost as old as mining, it was only when modern machines made possible the removal of vast tonnages of rock, that the support of underground workings--by filling worked-out stopes--became peremptory from both the humane and economic aspects.

General

All methods of back-filling with solids have been complicated by the presence of voids within the filled mass. It was to effect filling of voids in rock fills that selected mill tailing was first used. The earliest use of such tailing was to fill voids in coarser fills, and to create a fill that would permit mining operations near to and beyond the mined-out area. This entailed the filling of the mined-out area with slag or crushed rock, followed by the piping-in of mill tailing to complete the filling operation. In some instances, sloping diamond-drill holes connected by high-pressure hoses were used to transport the selected mill tailing to the desired fill area.

More recently, elaborate preparation plants and piping systems have been designed to prepare the tailing and to distribute it as back-fill to the desired fill areas. These plants usually consist of classifiers to separate the coarse sand from the final tailing, repulpers or agitators in which to prepare this sand for transporting underground, and the necessary controls
to regulate the flow of sand into tailing lines. The nature and weight of each tailing will determine the optimum density at which it will flow most readily without settling out in the long horizontal distances to the fill areas.

The most recent development in hydraulic back-filling is the use of unclassified mill tailing, which forms a more densely packed fill of sand and slime particles relatively impervious to additional water. This represents a fundamentally different approach to the problems of inhibiting the development of hydrostatic pressures within the fill. Thorough engineering studies must, however, be made before this system of filling can be recommended for general use.

Terminology

The following are descriptive definitions of terms used in connection with hydraulic filling:

Hydraulic filling—a system of filling underground excavations and cavities.

Hydraulic fill—fill that has been hydraulically placed.

Fill material—the material of which a hydraulic fill is composed.

Pulp—fill material mixed with water.

Fines—material suitable for use as a hydraulic fill.

Slimes—all minus 200-mesh material. (1)
Desliming——an operation which reduces the amount of minus 200-mesh material.

Bulkhead——a partition constructed to confine the fill material.

Filter bulkhead——a bulkhead constructed so as to permit drainage through it.

(1) All screen sizes refer to Tyler series.

Fill Materials Used

To be satisfactory for hydraulic filling, fill material must have a high ratio of fines and must not contain any boulders. The best results are obtained when material of small size — commonly below 10 mesh — is exclusively used. This material requires less water than fill of larger size, produces less wear on piping, and provides a superior fill when compared with waste-rock fill.

However, a combination of waste rock and hydraulically-placed classified mill tailing is said to give the most compact fill, as the classified mill tailing occupies 50 per cent of the void space in the rock fill, thus leaving only 25 per cent of the excavated area as void space in the final fill. However, an important disadvantage of this system is its potentiality for the building of hydrostatic pressure to a dangerous degree.
A similar hazard may be inherent in the recent employment of unclassified mill tailing. Correct filling practice may, however, produce a virtually impervious rigid fill that does not lend itself to development of hydrostatic pressures.

The following materials have been employed successfully in hydraulic filling systems: river sand, dune sand, granulated slag (also in combination with dump slag and mill tailing), classified mill tailing, and unclassified mill tailing.

**Hydraulic Filling Systems**

The hydraulic system of handling fill is continuous from surface to the location of placement, and no rehandling of materials is necessary. A hydraulic filling system requires only the installation of a preparation plant on the surface, apparatus for conveying the pulp underground, and the preparation of each stope for containing and dewatering the fill.

Advantages of hydraulic filling systems are summarized below.

1. Simplified and accelerated stoping cycle. The output of individual stopes has been increased as much as 50 percent.
2. Decrease in the non-productive portion of the working cycle.
3. Little labor required.
4. Involves a minimum of maintenance of equipment.
5. Permits filling in inaccessible parts of a mine.
(6) No dust hazard is introduced, and dust produced by blasting of stope ore is wetted by moisture from the fill.

(7) Does not interfere with underground traffic as the "fluid" tailing is delivered through an independent pipe system.

(8) No waste entries into stopes are required since fill-distributor pipe is installed in a service raise or manway.

(9) Relieves underground transportation system of the work involved in hauling waste fill.

(10) Cheaper mining methods.

(11) Reduced timber consumption.

(12) Greater recovery of ore.

(13) Less dilution by wall-rock.

(14) Decreased development per ton of ore mined.

(15) Less mine maintenance.

(16) Fill retains between 10 and 15 per cent moisture, which penetrates the mine timbers and reduces fire hazard (except where the fill material generates heat through chemical action).

(17) Facilitates better ventilation control.

(18) The filled stopes do not provide dead-air spaces. Wood buried in stopes resists decay.

(19) Hydraulic placing of sands gives a denser initial packing with a faster development of load-bearing qualities. This permits closer control of heavy walls and provides better rock support.
(20) Greater flexibility is provided for stoping of irregular ore blocks. Waste pillars and low-grade stope ends can be left in irregular shapes, and subsequent mining can go around or over them.

(21) Water-placed sands will immediately make a hard, level mining floor, and will stand unsupported for short vertical distances.

(22) Reduces the volume of mill tailing to be disposed of on surface and, subsequently, the tailing pond need not be as large.

Disadvantages resulting from tailing-fill practice are enumerated below.

(1) Stope faces are not on the line of air circulation and may thus require additional ventilation.

(2) Development waste usually must be hauled outside the mine.

(3) Increased volume of water must be pumped from the mine.

(4) Water in the ore chutes makes the broken ore sticky and hard to handle.

(5) Regardless of care, some sand slimes and fine ore (from ore chutes) will be washed into the haulageways and ditches below, which thus will require periodic cleaning.

(6) In scraping the surface of the fill, there is some dilution of the broken ore; there is also dilution from the
adjoining filled stopes.

(7) If water-placed sand does not drain either through its own characteristics or through lack of drainage facilities, it will assume the characteristics of a liquid and build up excessive hydrostatic pressures.

(8) Pressures at depth on the pipelines.

(9) Wear on the pipeline.

(10) Possible necessity of desliming the material.

(11) Suitable bulkheads have to be constructed.

Material deposited hydraulically flows into the small fissures and cracks in the adjoining rock and penetrates areas of broken rock or of matted timber and waste. The material is tight against the confining walls, except where the upper limit of the stope is nearly horizontal or very irregular. Low dips require more care during filling than do steep dips to assure tight filling and good drainage.
ATTRIBUTES OF HYDRAULIC FILLS

Cementation

Hydraulic fills exhibit a distinct lack of cementation but this does not significantly lessen the effectiveness of the fill. The time required for cementation is considerably longer for fine material than for coarse sand or waste. Thus mill tailings -- especially those with a high proportion of slimes -- may be expected to require many years for complete cementation. Most fills apparently are compressed to the maximum before sufficient time has elapsed for much cementing to take place.

The chemical composition and environment of a fill determine the effectiveness of cementation; results are thus seldom identical.

The methods of chemical soil solidification that have recently developed, may eventually prove valuable to hydraulic filling practice, especially as an emergency measure.

Compaction

Compaction refers to the consolidation of the fill material, exclusive of cementation. It depends chiefly upon the retained moisture and the slime content. The amount of moisture retained in a fully-drained fill may be as much as 15 per cent of the weight of the fill, but can be as low as 10 per cent.
The slime aids the compaction of a fill in two ways: it is important in retaining water (normally held by capillary action, and filling most of the voids), and it provides closer packing of the fill particles, the finer ones filling interstices. If the amount of slimes is too great, however, too much water may be retained and poor consolidation will result. If, on the other hand, the fill contains only a minor amount of slime particles, the consolidated fill will contain a large proportion of small air-filled voids and shrinkage cracks. Should water again reach the fill, the mass would be easily penetrated and resume its fluid state.

**Compressibility**

Hydraulically-deposited sands or other fine materials are the least compressible materials used for mine filling. Rarely do hydraulic fills compress more than 20 per cent; measurements and estimates generally indicate from 5 to 10 per cent. Hydraulic fills are more resistant than other fills because water-deposited particles form a compact mass, and because innumerable small particles provide a large bearing surface.

A hydraulic fill does not develop strength until sufficient dewatering has changed the material from the "fluid" to the consolidated condition. Pressure exerted on a poorly consolidated fill causes flowage and may be transmitted through the fill. Strong hydrostatic pressures may thus be exerted on the bulkheads.
Permeability

Permeability is important, and more so in large fills than in small ones. Large fills should either be impermeable, which they rarely are, or sufficiently permeable to allow the rapid dissipation of any water that may find its way into the fill, so that the water will not form ponds or otherwise be retained. Sufficient water in the fill, either from poor original dewatering or from subsequent influx, will cause a "fluid" condition and considerable hydrostatic pressures. Suitable permeability will permit any water that might enter to drain through fissures in the adjoining rock or through the drains provided in the bulkhead.

The permeability of small fills is less important because entrapped water may drain through less fill material, as the proportion of wall-rock and bulkhead surface exposed to the fill is much larger.

Percolation Rate

Due to pressure considerations, it is necessary to obtain a fill material with an adequate percolation rate (i.e. water-drainage rate) or to treat the material in such a manner that it will attain a required minimum percolation rate.

Sand for underground fill should have minimum percolation rates of 4 to 6 inches per hour.
Slime Content

Control of the amount of slimes in a fill material is very important. The permeability of a fill, and consequently the rate of percolation, depend chiefly on the slime content of the fill material. The slime content is a factor in the cementation and compaction of fills, and is also important for its effect on viscosity and abrasion during the transportation of the pulp. There is an upper limit to the amount of slimes that is satisfactory, although unclassified tailing has recently been employed with success.

In the case of fills that are comparatively coarse and contain few slimes, most of the dewatering is accomplished by percolation with final drainage of the water through the filter bulkheads.

Fills consisting of finer material require at least partial dewatering by decantation or by continual draining of water from the surface of the fill after these fills have consolidated. Only part of the water that is run in on the top of the fill will seep slowly into the fill; most of it will flow over the surface and seek an outlet elsewhere.

The effect of slimes has not been definitely correlated with the suitability of the fill. However, its effect in hydraulic filling is known to be great. There is probably a lower limit
of particle size below which the suitability of any material diminishes, especially if such sizes are present in too large quantities.
APPLICATIONS OF HYDRAULIC FILLING

Hydraulic filling can be used in almost any application for which conventional fills are used and is especially suited to certain uses. In most operations it serves more than one purpose, which may be

Control of Subsidence

Hydraulic fills are being employed to minimize surface damage, to permit mining below water-bearing formations, and to stabilize and protect underground workings. The effectiveness of hydraulic fills for support of the overlying strata is due to the strength and low compressibility of such fills.

Stopes Support During Mining

The quick, effective, support of stope walls reduces sloughing and slabbing, thus cuts down on dilution and generally makes for safer mining. It has also been possible to modify the mining method employed to permit savings in labor, timber and development work.

Pillar Recovery

The strong compressive strength of hydraulic fills, and the rapid succession of mining, filling, and taking weight makes hydraulic filling suitable for use in pillar recovery. The concentration of stresses in pillars is lessened by quick and
effective support so that mining proceeds rapidly, costs are reduced, safety is increased and the maintenance of access through pillars is facilitated.

Control and Prevention of Mine Fires

By inundating the entire area, in which the fire is burning, with hydraulic fill, many timber and sulfide fires in metal mines have been successfully controlled. This method is particularly effective with inaccessible fires of large extent and high temperature.

Drainage Control

The flow of underground water through solution channels and fissures into mines has been controlled by hydraulic filling. The mill tailing was introduced through boreholes into areas adjoining the mines.

Tailing Disposal

Where land is valuable, stream pollution is not desirable, or it is expensive to store tailing, disposal by hydraulic filling may be very economical. Tailing disposal has, however, never been the exclusive purpose of hydraulic filling.

Effects on Mine Ventilation

When hydraulic filling is used instead of filling with waste,
air does not short-circuit through the fill and the maintenance of openings required for ventilation is facilitated. Ventilation at stope faces may, however, become inadequate and necessitate auxiliary ventilation. The same is true for cases where slag is employed in the fill, the heat produced by oxidation requiring an increase in ventilation facilities. Hydraulic filling also increases the humidity of a mine and, therefore, may add to the ventilation problem.
Pulp Preparation

Fill material must be mixed with water at a pulp preparation plant before it is sent underground. The preparation plant regulates the volume or velocity, controls the pulp density, provides homogeneity in the pulp, and regulates the slime content.

Preparation plants can either provide a continuous flow of pulp or prepare the pulp in batches for intermittent delivery. The rate of feed controls the rate of output in a continuous type plant, and the efficiency of the unit is usually affected by fluctuations in the feed or discharge. In a closed-pipe gravity system, the rate of discharge varies with the depth and the horizontal distance to the point of placement. A continuous discharge system is thus practically restricted to use with large fills where the conditions are constant for considerable periods of time and where the pulp is transported in an open-pipe gravity system.

Pulp may be prepared by the employment of the different devices enumerated below.

1. Simple Sluicing Plants: In this type of plant, the material is simply sluiced from dumps, storage bins or leaching tanks into pipelines, boreholes, or launders. This method is simple and cheap and is particularly useful where the pulp is
introduced directly into stopes of shallow mines. It cannot, however, be controlled through long pipelines and is, therefore, not applied to small, widely-scattered fills.

2. **Thickeners, Classifiers, and Sand Cones:** Through the employment of these devices better control of the pulp is obtained than is possible in sluicing plants. They can be used in different combinations and permit the handling of large tonnages in a continuous operation.

3. **Agitation:** Agitators are widely used and provide a means of smoothing out surges in the feed to the pipeline. They are primarily employed to supply a homogeneous pulp, and are most effective where large volumes are handled and desliming is not important. Thickeners and classifiers are used in conjunction with agitators where the control of density and slimes is important.

4. **Dorrolones:** This classifying device is the most recent development used in preparation plants. It appears to have advantages over standard mechanical type classifiers in the way of lower capital costs for plant and equipment, and in the more thorough elimination of the finer material from the mill tailings consistent with a good recovery of the coarser portions.

5. **Underground Plants:** Dry material may be mixed into a pulp underground. Provision must, however, be made to get
the dry material underground, excavation for the mixing apparatus may be necessary, and the radius of filling operation is limited.

6. **Slime Ponds:** The ponding of slimes may be necessary where the mill tailing must be deslimed. An excellent pond may be constructed from the slimes themselves by permitting localized drying and shoveling the slimes into dykes, where they make a tough leathery bank.

**Pulp Distribution**

The pulp may be distributed by several methods. These include gravity system -- employing pipelines, boreholes, or launders -- and pumping systems, or a combination of these. The choice of a system is determined largely by the layout of the mine and plant, the tonnage requirements, and the physical character of the pulp, especially the settling rate and abrasiveness.

In all systems, the pulp density should be as high as possible to minimize the amount of water introduced into the mine; it is usually limited to the density at which plugs and spills occur. The velocity should be as low as possible in order to minimize wear and yet handle the required tonnage.

The transportation systems employed are described below.

1. **Closed-Pipe, Gravity Systems** (see Fig. 1): The most common means of conveying the pulp underground is through a closed piping system in which there is no break nor opportunity for air to enter: the pulp flows at a constant velocity through-
Fig. 1. -- A Closed-Pipe, Gravity System
out the length of the line if the pipe size remains the same. This system has been chiefly used with the strict batch-agitation preparation plant for which it is ideally suited. Surging and heavy vibration do not occur in a closed-pipe system.

The interrelations of density, viscosity, and friction are important once such a system has been installed; they control the tonnage (which may not be too great) and the velocity. Variations in the location of underground discharge necessitate regulation of the pulp density.

2. Open-Pipe, Gravity Systems: An open-pipe system is so constructed that air enters the pipeline along its length, so that the pulp drops freely (not entirely) in the upper parts of the vertical sections and the velocity varies along the line. This system is applicable where large tonnages are handled and where larger pipe sizes are used.

The discharge velocity in such a system is usually higher than the calculated value and it is often violent. Pipe wear is heavy and non-uniform, and vertical sections require strong support to check vibration.

The ratio of horizontal length to elevation head is important in all gravity systems. The horizontal run should not be more than 3 to 4 times the vertical fall as there will be difficulty due to stoppages from settling of sands.
3. Pumping Plants: The pumping of hydraulic fill is similar to the pumping of suspensoids, except that higher pulp densities are used. Some pumping of pulp is necessary at most mines. The pulp density usually varies considerably depending on the distance and the amount of seawater introduced by the pumps.
MINING METHODS

CUT AND FILL STOPE
SHOWING STANDARD STOPING CYCLE

Fig. 2. -- Stoping Cycle, Cut-and-Fill Stope

Fig. 3. -- Stoping Cycle, Open Stope
COSTS

Cost data for hydraulic filling are difficult to obtain and to correlate. The cost figures range within wide limits and only the most general conclusions can be drawn. The cost per ton of fill deposited at mines that place small fills is higher than at mines where large fills are placed. The cost is lowest per ton where large volumes are handled, a minimum of bulk-heading is necessary, gravity handling is employed, the system is run as nearly continuously as possible, current mill tailing is used, and the depth is not excessive.

Table 1 shows the costs of hydraulic filling per ton of dry fill deposited, each from a different mine. The year is given to establish the general level of economic conditions at the time.

Table 1

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<th>Date</th>
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CONCLUSIONS

Although some other method of filling may be preferable at some mines, hydraulic filling has wide applications for many kinds of mining and for many different purposes. It has been used in coal mining, ferrous and non-ferrous metal mining, and undoubtedly could be employed in the mining of non-metals. It has been used in steep veins, narrow seams, wide lodes, massive ore bodies, and in bedded deposits. Apparently no hydraulic filling operation connected with metal mining has ever been unsuccessful, either technically or economically.
BIBLIOGRAPHY


