Underground Concreting

J. D. Riggleman

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Report
Submitted to
Professor K. S. Stout

UNDERGROUND CONCRETING

by

J. D. Riggleman

May 11, 1956
Montana School of Mines
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May 11, 1956
Montana School of Mines
Butte, Montana
May 11, 1956

K. S. Stout, Mining Professor
Montana School of Mines
Butte, Montana

Dear Mr. Stout:

In accordance with your request, I submit this report project, Underground Concreting.

Most of the material contained in the report was obtained from various articles and books concerning concreting; however, some of the information is that gained from personal observations of concreting operations.

Emphasis has been placed upon the fundamentals of concrete mix, design, and placing.

Sincerely,

J. D. Riggileman
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Letter of Transmittal</td>
<td>ii</td>
</tr>
<tr>
<td>List of Illustrations</td>
<td>iv</td>
</tr>
<tr>
<td>Introduction</td>
<td>v</td>
</tr>
<tr>
<td>I. CONCRETE</td>
<td>1</td>
</tr>
<tr>
<td>A. Cement</td>
<td>2</td>
</tr>
<tr>
<td>B. Aggregates</td>
<td>5</td>
</tr>
<tr>
<td>C. Water</td>
<td>6</td>
</tr>
<tr>
<td>D. Characteristics</td>
<td>7</td>
</tr>
<tr>
<td>E. Mix Design</td>
<td>9</td>
</tr>
<tr>
<td>F. Mine Use</td>
<td>10</td>
</tr>
<tr>
<td>G. Wetting Agents</td>
<td>11</td>
</tr>
<tr>
<td>H. Reinforcing</td>
<td>12</td>
</tr>
<tr>
<td>II. PLACING</td>
<td>13</td>
</tr>
<tr>
<td>A. Pneumatic</td>
<td>13</td>
</tr>
<tr>
<td>B. Mechanical</td>
<td>15</td>
</tr>
<tr>
<td>C. Forms</td>
<td>17</td>
</tr>
<tr>
<td>III. CONCRETING UNDERGROUND</td>
<td>20</td>
</tr>
<tr>
<td>A. Shafts</td>
<td>20</td>
</tr>
<tr>
<td>B. Tunnels and Slusher Drifts</td>
<td>22</td>
</tr>
<tr>
<td>C. Stopes</td>
<td>23</td>
</tr>
<tr>
<td>D. Ore Pockets</td>
<td>23</td>
</tr>
<tr>
<td>E. Sumps</td>
<td>23</td>
</tr>
<tr>
<td>IV. CONCLUSION</td>
<td>24</td>
</tr>
<tr>
<td>A. Cost</td>
<td>24</td>
</tr>
<tr>
<td>B. Summary</td>
<td>26</td>
</tr>
<tr>
<td>V. FOOTNOTES</td>
<td>27</td>
</tr>
<tr>
<td>VI. BIBLIOGRAPHY</td>
<td>29</td>
</tr>
<tr>
<td>VII. APPENDIX</td>
<td>31</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Fig.</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Acceptable Fine Aggregate Before and After Separation by Sieves</td>
<td>32</td>
</tr>
<tr>
<td>2.</td>
<td>Relation of Compressive Strength to Water Content</td>
<td>32</td>
</tr>
<tr>
<td>3.</td>
<td>Comparison of Calcium Chloride Concrete with Plain Concrete</td>
<td>33</td>
</tr>
<tr>
<td>4.</td>
<td>Early Flexural Strength Gains Caused by Calcium Chloride</td>
<td>34</td>
</tr>
<tr>
<td>5.</td>
<td>Increase in Early and Ultimate Strength of Calcium Chloride Concrete</td>
<td>35</td>
</tr>
<tr>
<td>6.</td>
<td>Comparison of Calcium Chloride Concrete and Plain Concrete with Respect to Water Loss During Setting</td>
<td>36</td>
</tr>
<tr>
<td>7.</td>
<td>Workability and Density of Calcium Chloride Concrete Compared with Plain Concrete</td>
<td>37</td>
</tr>
<tr>
<td>8.</td>
<td>Pneumatic Placer Underground</td>
<td>38</td>
</tr>
<tr>
<td>9.</td>
<td>Guniteing Underground</td>
<td>39</td>
</tr>
<tr>
<td>10.</td>
<td>Pumcrete Machine and Valve Action</td>
<td>40</td>
</tr>
<tr>
<td>11.</td>
<td>Standard Straight Sections and Elbows Used in Pipeline Concreting</td>
<td>41</td>
</tr>
<tr>
<td>12.</td>
<td>Burlap Go-devil Used in Pneumatic Placing</td>
<td>41</td>
</tr>
<tr>
<td>13.</td>
<td>Concrete Batching Plant at Mather &quot;B&quot; Shaft</td>
<td>42</td>
</tr>
<tr>
<td>14.</td>
<td>Wooden Concrete Forms</td>
<td>43</td>
</tr>
<tr>
<td>15.</td>
<td>Hydraulically Operated Steel Forms</td>
<td>44</td>
</tr>
<tr>
<td>16.</td>
<td>Steel Forms for Shaft Concreting</td>
<td>44</td>
</tr>
<tr>
<td>17.</td>
<td>Steel Forms Underground</td>
<td>45</td>
</tr>
<tr>
<td>18.</td>
<td>Installation of Reinforcing Steel in a shaft</td>
<td>46</td>
</tr>
<tr>
<td>19.</td>
<td>Water Ring in a concrete Shaft</td>
<td>47</td>
</tr>
<tr>
<td>20.</td>
<td>Pipeline Concreting in a shaft</td>
<td>48</td>
</tr>
</tbody>
</table>
INTRODUCTION

Concreting has in the past few years become a prime consideration in underground support; therefore, this report will endeavor to outline some of the basic fundamentals of underground concreting.

Greater emphasis has been placed upon the characteristics and criteria of good concrete and placing procedures and techniques. Actual examples of practice have been cited, but only to illustrate the basic fundamentals which are outlined in the major part of this report.
CONCRETE

Concrete is an artificial stone, cast in place in a plastic condition. Its essential components are cement, water, sand and gravel. These ingredients react with each other, especially the cement and water, chemically to form a material which possesses structural strength. In the concrete engineer's vernacular, different combinations of these ingredients are given special names. A mixture of cement and water is called cement paste, a relatively expensive mixture. In order to reduce the cost of the cement-water mixture, inert filler materials known as aggregates, are added. Grout, a mixture of fluid consistency, is composed of a large amount of cement paste to which a small amount of fine aggregate has been added. When the amount of fine aggregate or sand is increased to the point where the mixture is no longer fluid, the resulting mixture is called mortar. Addition of coarse aggregate, or gravel to mortar gives the combination of the essential ingredients and is termed concrete.

Mixtures of concrete are differentiated from each other by the designation of the comparative amounts of cement, fine aggregate, and coarse aggregate contained in each mixture. In order that a standard terminology of concrete mixtures is used, the ingredients are always indicated in the same order: cement, fine aggregate or sand, and coarse
aggregate, or gravel. For example a 1 : 3 : 4 concrete is a mixture composed of 1 cu ft of cement, 3 cu ft of fine aggregate, and 4 cu ft of coarse aggregate plus an unspecified amount of water. A proportion of 1 : 4 would indicate 1 part of cement to 4 parts of fine aggregate and would be termed mortar. This method of specifying concrete mixtures by volumes has large application in small jobs, but for larger jobs of concrete placement the specifications of mixtures are in the same order but the proportions are by weight. A typical proportion by weight would be written as 94 : 180 : 350 lb. Sometimes in the larger and more exacting jobs even the amount of water to be used in mixing is specified. Water, as will be shown later, is the main determining factor, besides cement, in strength of the concrete.

Before going further into the characteristics of concrete, a brief discussion of the characteristics of the components of concrete will follow.

Cement

Man has been using cementaceous material in building important structures for more than two thousand years. These cementing materials may be divided into two main classes: non-hydraulic and hydraulic. Non-hydraulic cements, as the name implies, will not set or harden under water; while hydraulic cements will harden in either air or water.
This discussion will concern itself primarily with the hydraulic cements because these are the cements which are used in mining operations. The following is a list of the structural cements of commercial importance:

Non-Hydraulic

Gypsum plasters

Common lime

Hydraulic

Hydraulic lime

Puzzolan cement

Natural cement

Portland cement

Hydraulic lime is made by burning argillaceous or siliceous limestone at a temperature not less than 1000° C. The product is showered with water and a slaking action takes place with little change in volume. This product has hydraulic qualities due to the combination of calcium and silica into calcium silicate. This type of hydraulic cement is used in architectural design because of its non-staining qualities.

Puzzolan, or slag cement is made by adding hydrated lime and a siliceous material, such as fine granulated blast-furnace slag. This type of cement is slow setting and not as strong as Portland cements. Many European countries use puzzolan cement in underground structures where weight and bulk are more important considerations than
strength.

Natural cement is made from rocks as it occurs in nature. The rock is an argillaceous limestone. Burning the rock at 900° C to 1300° C and pulverizing the clinker, produces a non-slaking product with strong hydraulic properties. The disadvantage of natural cements is that there is a great variation in the quality of the cements from different localities. This type of cement is also used in underground installations where high stresses will not be imposed for several months after placement.

Portland cement is made by finely pulverizing the clinker by burning a definite mixture of siliceous, argillaceous, and calcareous materials to a point beyond the fusion temperature of the mixture. The essential components of Portland cement are obtained from different sources, but the proportions of the different Portland cements is constant within narrow limits. Percentages of the principal components of Portland cement range as follows:

\[
\begin{array}{cccccc}
\text{SiO}_2 & \text{Al}_2\text{O}_3 & \text{CaO} & \text{MgO} & \text{Fe}_2\text{O}_3 \\
19-25 & 5-9 & 60-64 & 1-2.5 & 2-4 \\
\end{array}
\]

Portland cement is by far the most important cementing material used in modern engineering construction. It is adapted to use in mortar and concrete in all types of structures, especially underground, where strength and resistance to wear are of special importance. Reinforced-concrete construction should invariably use Portland cement because
of the cement's high early strength and general uniform qualities.

**Aggregates**

Aggregates compose approximately 90% or more of the substance of concrete; therefore, the characteristics of the aggregate must at least equal the properties desired in the concrete. These aggregates must be hard, durable, strong, and for most cases insoluble. They must have rough enough surfaces for good bonding of the cement. A good clean aggregate is imperative for good concrete, because if the aggregate is dirty an incomplete adhesion between cement and aggregate will result in poor concrete.

As stated previously, aggregates are classified in two groups which are based upon size. Coarse aggregates are particles of gravel, crushed rock or other material above 1/4 in. diameter. Any crushed rock or clean, hard, natural gravel, not subject to disintegration is suitable for a coarse aggregate. Three types of rocks are suitable for coarse aggregates: granite and other igneous rocks, sandstones and other sedimentary rocks, and limestone and related rocks.

Since stone is the strongest constituent of concrete, the greater the percentage of stone that is in the concrete the stronger the concrete will be; that is, theoretically, as the percentage of stone in concrete increases, the nearer
concrete approaches natural stone in strength and density.

There are certain limitations upon the size of stone used in certain types of work. In reinforcement work, the concrete must fit plastically around the reinforcing metal; thus 1 to 1.5 in. is the greatest diameter of stone that should be used. In large mass jobs larger stone can be used to better advantage with uses of less cement.

Fine aggregates are those particles below 1/4 in. in size. These fine aggregates are essentially rock fragments, crushed to fineness either by natural processes of weathering, disintegration, glacial action, or by machinery. Quartz sand is the best rock for making high quality concrete. Figure 1 shows an example of good fine aggregate for concrete.

In summary, aggregates must be clean, of proper size, hard, insoluble in water, dense, and structurally strong. Contrary to popular belief aggregates that are angular in shape are not needed for superior concrete.

Water

The use of water, as stated previously, is the most important consideration in making good concrete. Water used in making concrete should be free from oils, acid, alkali, and vegetal matter, and should be of a quality fit for human consumption.

The functions of water in concrete are the following:

1. Water reacts with cement to form a binding material which binds together otherwise noncohering coarse and fine aggregates.
2. Water operates to flux dissolved and undissolved cementing substances over the surfaces of sand grains and stone particles. This fluxing action renders possible extensive and close adhesion by carrying cement into the small and multitudinous surface irregularities of the particles.

3. Water acts as a lubricant between gravel and sand particles so that placement of the concrete in forms and molds is facilitated.

4. Water itself occupies space in the concrete mass. The first function of water is basic to manufacture of good concrete. Insufficient water in concrete will result in an incomplete reaction and if there is too much water the cementing products are too dilute to develop proper strength during the initial stages of setting. Cement strength depends to some extent, upon interlacing of crystals; and crystallization takes place only from saturated or supersaturated solutions. If too much water is added to a mix this crystallization is reduced and the resulting bond is not as strong as it could be.

The function of water as a flux and lubricant of concrete is very important, but their importance can be overestimated, particularly when balanced against the detrimental effects of too much water.

**Characteristics**

Time of setting of concrete is another characteristic which should be dealt with in any discussion of the characteristics of concrete. A concrete may set so quickly that it is worthless for use as a structural material, since
handling concrete after it starts to set weakens it and causes it to disintegrate, or it may set so slowly that it will delay the progress of work too much.

Aside from the consideration of the age of the cement, the following are conditions which accelerate the setting of concrete: finely ground and lightly burned concrete, dry atmosphere, and high temperature of air and water. Two distinct stages exist in the setting of concrete. They are the following: the initial set and the hard or final set. The best cements should be slow in taking the initial set but after the initial set is accomplished the hardening should proceed rapidly. Portland cement should acquire the initial set in not less than 45 minutes and the hard set in not more than 10 hours.

Concrete is said to have its initial set when it will not thoroughly reunite along the surfaces of a break. It has taken its final set when it begins to have appreciable strength and hardness.2

Figure 2 shows the relation of compressive strength to water content of concrete. The figure is based upon tests made upon concrete specimens after a 28 day interval -- a standard concrete testing procedure.3 Conservative safe strength of Portland cement concrete in compression is shown in the following table:4

<table>
<thead>
<tr>
<th>Proportions</th>
<th>Pounds per square inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1 1/2:3</td>
<td>500</td>
</tr>
<tr>
<td>1:2:4</td>
<td>450</td>
</tr>
</tbody>
</table>
Proportions (cont.)  Pounds per square inch
1:2 1/2:5  400
1:3:6  360
1:4:8  290

Concrete has very poor resistance to tensile loads; therefore, in any structure which may be subjected to tensile or severe bending stress reinforcing steel must be used. For example, tests of a concrete having a fairly rich cement content and an ultimate compressive strength of 4,840 lb per sq in. at 28 days had an ultimate tensile strength of 317 lb. per sq in.

Another characteristic of concrete with which management is always concerned is the ability of concrete to withstand heat. Concrete is incombustible and a poor conductor of heat. This incombustibility of concrete is in many cases a large determinant in management's decision to use concrete underground. Concrete is also considered to be a permanent type of support and thus, maintenance costs are cut practically to nothing. The permanence feature of a concrete shaft is very great in comparison to timbered shafts in reducing maintenance where there is falling rock due to loading and unloading skips.

Mix Design

For many jobs standard mixes are used. A rich mixture would be 1:1:5:3 and is used in structures requiring high strength characteristics or high water resistance characteristics. Standard mixes above 1:2:4 are also water resistant
but they are used where above normal strength is required.
For ordinary concrete jobs not requiring extra strength or
high water resistance, a medium mix, 1:3.5:5, is used.
Lean mixtures, 1:3:6, are employed in heavy, massive foun-
dations and structures not requiring very strong concrete.5

The most used method of estimating the quantities of
cement and aggregate required for a given volume of concrete
is by the use of an empirical formula proposed by W. F.
Fuller.

\[
C = \frac{11}{c+s+g}
\]

\[
S = C \times s \times 3.8
\]

\[
G = C \times g \times 3.8
\]

where:  
C = number of barrels of cement per yard of
concrete.  
S = number of cubic yards of sand per cubic
yard of concrete.  
c:s:g: = the proportion of cement, sand and
coarse aggregate.

This formula is based upon measurement of loose aggre-
gate and for well graded aggregates gives slightly greater
amounts than are actually required.6

Mine Use

Usually, for underground concreting jobs rich or stan-
dard mixtures are used. That is, either 1:1.5:3 or 1:2:4
mixtures are used because of the added strength and corrosion
resistance needed in underground installations. In most
instances where reinforcing is used a rich mix is used.
Calcium chloride is used in concrete, especially in most underground jobs where a high initial strength is needed. It effectively reduces the time required for the concrete to take its initial and final set. The first noticeable effect of the addition of 2 per cent calcium chloride by weight of Portland cement on concrete is the reduction in time required for initial set. The time is reduced by $2/3$ ds under normal conditions—from 3 hours to 1 hour. The final set is reduced by the same ratio—from 6 hours to 2 hours. At lower temperatures the actual time of set is slower, but the accelerating effect of calcium chloride is more pronounced. At 70° F the use of calcium chloride more than doubles the one day strength of concrete. It produces greater strengths of approximately 50 per cent at 3 days and 30 percent at 7 days.

Workability and density can be increased by the use of calcium chloride in the mix. Where increased workability is desired, the water : cement ratio is maintained without change when calcium chloride is used, but when increased density is desired the water content can be reduced up to one-half gallon per bag of cement without loss of workability. Figures 3-7 show some of the properties of calcium chloride concrete.

Wetting Agents

Wetting agents, or dispersing agents, are used in concrete to increase the ease of flow, durability by making a more
dense concrete, and the strength. The strength of concrete is increased by 20 per cent by the addition of wetting agents.

One commercial agent, Pozzolith, a calcium lignosulfonate, is most commonly used in concrete work. This agent increases resistance to freezing and thawing up to 400 per cent. This is done by reducing the permeability of the concrete and entraining an optimum amount of air.

Reinforcing

Steel is used in combination with concrete when the concrete is apt to be subjected to tensile stresses. A brief discussion of steel will follow before the combination of steel and concrete is discussed.

The reinforcing steel in reinforced concrete construction is mostly in the form of rods, or bars, of round or square cross-section. These rods or bars vary in size from 3/8 in. for light construction to 1 1/4 in. as a maximum size for heavy construction. Both plain and deformed bars are used but the deformed bars give a better bond between concrete and steel because there is more adhesion due to the deformation of the bar. Wire fabric is used to a considerable extent in connection with gunite in some places underground. Salvaged mine rails are also used with concrete in slusher drifts; however, the main function of these rails is not for reinforcement but for wear resistance.

The highest success in the use of steel and concrete in combination is attained when maximum strength is obtained
at minimum cost. Steel can be put into a form to resist tensile stress much more cheaply than it can be put into a form to resist compressive stress. This should be clear when it is considered that the solid bar is well adapted to take tensile stresses, while for compressive stresses the steel must have a larger cross-section in order to provide the necessary lateral rigidity.

Concrete and steel in combination work very satisfactorily unless the combination is subjected to sudden violent shock pressures, such as that which would come from blasting on or near the structure. The difference in moduli between the two materials makes it impossible to maintain a good bond when blasting is done on or near rein forced concrete; consequently, in areas where much blasting is done either concrete or steel is used alone for support.

Some objections arise to the use of steel because it can be corroded and it does not stand up to heat. Concrete on the other hand, cannot be used in tension, but its compressive strength is fairly high. It is also fireproof and has great durability. Tests have shown that concrete thoroughly protects embedded steel from corrosion and failure due to heat.

PLACING

Pneumatic

Placing and transporting concrete are probably the two most important determining factors in the cost analysis of
concrete support for mine workings. Inefficient handling of the concrete after it goes down the shaft many times makes the cost of concrete support too high. During the first days of concrete work underground, concrete was transported and placed by slow mechanical methods. Soon after, however, placer (Fig. 8) machines were developed which enabled mine crews to place and transport concrete as far as 2000 ft from the mixing station. This method is far superior to the handling of concrete in mine cars, although in some cases the costs of equipment for pneumatic placing is high. A placer consists of a hopper into which a batch of mixed concrete is poured. An air tight top placed over the top of the hopper allows air pressure to be introduced into the machine. This air pressure forces the concrete in a slug through the pipe into the forms.

Guniting, a process by which concrete or mortar is mixed and applied in one operation, has steadily increased in importance since it was developed in the early 1900's. Basically, gunite is pneumatically placed concrete conveyed by compressed air to a "gun" where water is added and the hydrated mixture blown into position. Figure 9 shows gunite being applied. Gunite is an extremely dense tightly-packed, concrete. This characteristic of gunite makes it especially applicable in covering the walls and back in underground motor barns, pump rooms, generator rooms, and wet haulage drifts.
Mechanical

The most important mechanical placing device, probably, is the pumpcrete machine. This machine is a heavy-duty, single-action piston pump of conventional crankshaft and connecting rod design. The bore of the piston ranges approximately from 6 to 8 in. and operate with a 12 in. stroke at 50 strokes per minute. The cylinder is horizontal with the discharge valve and pipe line connection directly in line with the piston's travel. The pipe line must be nearly the same size as the piston because concrete offers a great resistance to any compressing force. The valves shown in Figure 10 are timed with relationship to the movement of the piston. Of course the internal parts of a machine such as this which would be subject to abrasion are replaceable.

Gravity feed, especially in shaft sinking, is important in any consideration of placing of concrete. In shaft concreting no large difficulties arise from gravity transportation of concrete, but in gravity transportation of concrete down a shaft and onto a level does pose a problem. This problem stems from the abrasive action of concrete on pipe. Many experiments have been made in regards to elimination of high destructive abrasion in pipe lines at turning points or angles in the line. Ordinary steel pipe elbows wear out in a matter of minutes and expensive nickel-steel elbows and turns last a comparatively short time also if special precautions are not taken. To negotiate a corner
short turns are desirable but in some instances 45° elbows are used with much more success. Another abrasion reducer, employed especially at the bottom of a vertical pipe taking concrete down, is the air cushion effect. This effect is obtained by installing a short extension on the first elbow. This allows an air cushion to form and thus reduces much abrasion. Figure 11 shows some standard straight pipe sections and elbows used in concrete piping operations.

Upon the completion of a pour of concrete the pipe line must be cleaned of all concrete left in the pipe. Air is used for this operation on all underground work. Surface work usually makes use of water in cleaning. Standard go-devils are not put in the pipe when compressed air is used because of the high force that is exerted by the compressed air; instead a tightly rolled plug of wet burlap is forced through the pipe. Figure 12 shows a pipe set up for cleaning with compressed air. Ninety pounds of air is usually high enough pressure to clean approximately 450 ft of pipe.

In summary the advantages of using pipeline concrete are as follows:

1. Interference with normal mining operations is eliminated. When cage, skips, mine cars or mine openings are used for transporting concrete mine operations suffer in one way or another.

2. When concrete can be delivered underground at reasonable cost, it can be used to replace more expensive materials. Mine timber, one of the mining supplies that has increased considerably in cost during the last few years, can be eliminated and replaced by concrete for mine support.
3. When concrete is used for ground support, the men have neater, cleaner, and safer working conditions.

Figure 13 shows the pipeline layout for the Mather Mine "B" shaft.

In other mine installations needing concrete, sometimes it is possible and economically feasible to transport the concrete in cars and place the concrete in the ordinary manner, that is, without the use of pipe line and placing machines. An example of this practice would be in the concreting of a sump where a fairly small amount of concrete would not warrant an expensive pipe line and placing machine.

Forms

Forms in connection with concrete placement are a large factor both with respect to the cost of fabrication and the expense in time and money involved in setting up and removing them. Because time is of such great importance in underground operations, it is necessary for mine management to secure forms that will do the job and take a minimum of time for installation and removal. Of course, the initial cost of forms is a consideration in the selection of forms for underground concrete work also.

Forms for underground work are fabricated from the following materials: wood, steel and aluminum. Wooden forms predominate in most ordinary concreting practices because of the low initial investment. Figure 14 shows a
typical wooden form used in concreting drifts. As shown in Figure 14, any drift concreted using this form would shut down any haulage through it during concreting operations. Thus, companies have devised wooden forms which can be used and still permit haulage. These forms consist of 3 in. lagging placed horizontally along the drift with 3 or 4 3 in. lagging across the horizontal lagging. Wire rope is used to secure the lagging to withstand the outward pressure of the concrete. A recent development in wooden forms is being used in Sweden with much success. Special tongue and groove boards are made so that they lock together. The whole form is carried by a yoke to which hydraulic jacks are connected. These hydraulic jacks make it possible to slide the forms up evenly over the concrete then, a continuous operation can be obtained. As yet, this method of continuous pouring and sliding forms have been used only in shaft construction, but variations of the idea has been incorporated into some forms for concreting drifts. Figure 15 shows a hydraulic form in place.

Using the type of form shown in Figure 15, the concreting cycle consists of pouring 20 ft one day, stripping and moving the forms up the next day, and pouring again on the next day.¹²

Aluminum within the last few years, has come into use as a form fabrication material. The advantages of aluminum
forms are the following:

1. These forms are light and require less effort to move them.

2. Aluminum is quite strong for its weight.

3. The cost of aluminum sheeting and aluminum braces is not prohibitive.

4. Aluminum is easily formed and fabricated.

Forms made of steel are used in many underground operations where a large number of similar concreting applications are made. Steel as well as aluminum forms are either of the pre-formed type or they are fabricated in the mine. Prefabrication has the advantage that forms are made where building is facilitated by unlimited working space and special shapes found on surface. Of course, in most circumstances except for shafts, it is impossible to take a completely fabricated metal drift form down a shaft; consequently, most metal forms are fabricated on surface into sections and final fabrication is accomplished at the working place. Figure 16 shows a pre-fabricated steel shaft form on surface. Figure 17 shows a sectional steel form that has been completed underground.

In summary the desirable features of good concreting forms are as follows:

1. The forms should be easy to set up and tear down. Much of the cost of concreting is incurred by labor in putting up and tearing down forms.
2. Mobility of forms without complete tear down is desirable in forms. In many cases this mobility is accomplished by mounting the form supports on wheels which fit on the haulage track.

3. The cost of fabrication of forms should not be excessive, that is, the forms should not wear out before a normal life is obtained from them.

4. Finally, an ideal form would have corrosion resistance, because in many mines, especially sulfide mines, the mine water is very corrosive and the life of a non-resistant form is reduced.

CONCRETING UNDERGROUND

Shafts

The modern trend in shaft support is toward the use of plain and reinforced concrete. The characteristics of permanence, maintenance, fire resistance, corrosion resistance and durability have been discussed previously and are the main reasons for the use of concrete in shafts.

Forms used in conjunction with shaft concreting have also been previously discussed. Most concrete shafts being sunk today are either circular or elliptical in shape. The reason for the trend toward circular shafts are as follows:

1. Better ventilation properties are attained in circular shafts.
2. Circular structures can withstand higher compressive stresses as compared with square or rectangular structures.

3. A high rate of sinking can be obtained in circular shafts due to the circular tracks installed with mechanical muckers.

Many large shafts are reinforced because of the greater strength that reinforcing steel imparts to concrete. Figure 18 shows workers installing reinforcing rods in a shaft which is to be concreted.

Placing concrete in shafts can be done starting either from the top or bottom. Concreting from the top towards the bottom has the obvious advantage of simultaneous concreting and mining operations. Concreting from below towards the top can start as soon as the mining operations are far enough down. Bearing sets and water rings are installed at intervals along the shaft. A typical water ring installed in a concrete shaft is shown in Figure 19. Concrete is either pumped by pipe down the shaft as shown in Figure 20 or it is lowered down in buckets and put into a hopper from which the cement is distributed into the forms.

The 12 man-shift working cycle for the concreting of the Anaconda Company Kelley Supply Shaft in which the timbers were used for forms is as follows:

1. Remove blocking stringers from set above, jack the set into line and re-block, using butt blocks.

2. Remove divider forms and panel lagging from two pours below and install divider from above.

4. Place reinforcing steel in position and tie.

5. Install panel lagging, cleats, and braces.

6. Pour concrete.

The concrete was delivered from a 4 in. pipe line to the forms through a heavy duty 6 in hose which was hooked over the end of the pipe. As the pour progressed the hose was moved from one side to the other to maintain a uniform hydrostatic head. A pneumatic vibrator forced the mix to flow around all fixtures and reinforcing without voids.

Tunnels and Slusher Drifts

As stated before, concreting of tunnels and slusher drifts has many advantages over timber support. Additional advantages are the following:

1. Less experienced timbermen are required for both original placement, and occasional repair to finger openings in slusher drifts.

2. Development of haulage and slushing drifts can be far in advance of that work which is actually required with no deterioration of the development workings. This is advantageous during shut-downs.

3. The driving of both slushing and haulage drifts with an arched section has permitted the drifts to stand unsupported until they can be lined with concrete.

4. Again the fire hazard is eliminated. Hydraulically operated steel and aluminum forms, as shown in Figure 16, can be used in either small drifts or large drifts by the removal or addition of the bottom plates.

An example of the concreting cycle used at Number 4 mine in Cornwall Pa., in a drift has been previously cited so no example of underground practice will be given here.
Stopes

Concreting done in connection with stopes is usually in connection with the chute mouth. Because the maintenance cost of chute mouths is very high, concreting has come to play an important part in reduction of these high costs. Wear in the bottom of the chute mouth or lip is reduced by using steel wear bars. Blocks have been used in stopes and drifts for stoppings and wall structures. The blocks are usually 8 in. by 16 in. and are made of sand and gravel or crushed stone or cinders. This type of masonry is more economical than other types of masonry because it requires less labor and mortar to put a given number of square feet of wall.

Ore Pocket

Ore pockets and ore-transfer raises, if they are to handle a large volume of ore, must in some way be provided with a wear resistant liner. Concrete reinforced with salvaged mine rails makes an excellent lining for these places. An extra thickness of concrete, a minimum of 18 in., should be used on the lower part of the ore pocket and transfer because of the increased wear due to falling rock.

Sumps

Sumps require a rich mixture of concrete because of the necessity for a water proof receptacle. A rich mixture will also give added resistance against corrosive mine waters often found in metal mines.
CONCLUSION

Cost

Determination of the total cost of concreting will be somewhat limited in scope because of the limited material to be found on this most important phase of the concreting picture. In most instances, any cost data gathered from different sources vary widely because of the lack of standardization of cost analysis in different companies. Fixed costs such as those for materials—cement, aggregate, wetting agents, reinforcing steel and form material are fairly constant in different cost analyses, but it is in the figuring of the indirect costs that the great variation in total cost occurs. It is difficult in many instances to determine from the data given what things are included and what things are left out of the total indirect cost. For example, of two companies using pre-fabricated forms, one company may elect to include the cost of fabrication in the indirect cost; whereas, the second company may choose to leave fabrication costs out of their tabulation of indirect cost.

The following costs are, therefore, as of necessity, relative and might not contain all costs incurred in the concreting process. Costs tabulated are for 1950 material and labor prices; therefore, it is reasonable to assume that they are slightly lower than present-day costs.
TABLE I

Costs of concrete lined slushing drifts at Number 4 mine, Cornwall, Pennsylvania.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lineal feet</td>
<td>1,388.5</td>
</tr>
<tr>
<td>Total manshifts</td>
<td>1,607.5</td>
</tr>
<tr>
<td>Cubic yards concrete</td>
<td>1,910.5</td>
</tr>
<tr>
<td>Manshifts per ft</td>
<td>1.16</td>
</tr>
<tr>
<td>Cubic yards per foot</td>
<td>1.38</td>
</tr>
<tr>
<td>Labor cost per foot</td>
<td>13.73</td>
</tr>
<tr>
<td>Material cost per foot</td>
<td>14.15</td>
</tr>
<tr>
<td>Total cost per foot of concrete</td>
<td>27.88</td>
</tr>
</tbody>
</table>

Total cost per cubic yard of concrete placed --- 20.20

The size of the drifts are 6 ft by 7 ft. Most of the concrete was poured by a placer on the surface. Labor rates averaged $11.84 per manshift and concrete cost $10.75 per yard at the shaft collar.16

Labor costs are approximately 49.3 per cent of the total cost per foot of concrete while the cost of materials makes up the rest of the cost.

The original investment in equipment has not been considered in this cost evaluation but the approximate cost of this equipment at today's prices is $13,000. Maintenance of the equipment is a fairly large item in placing concrete by pipeline because of the high abrasion of concrete on pipes and machine parts. Nickel-steel turns in pipeline will usually last about 5 months before they have to be replaced. Turning the pipeline a quarter of a turn at certain time intervals during pouring assures even wearing of the pipe and reduces cost of pipe.
SUMMARY

Concrete and its use underground have a bright future. The modern day trend is toward a support that will fill in the void left by removal of rock and as nearly as possible return the ground to stable conditions. This stabilizing effect is obtained by driving underground openings approximating the stabilized arch condition and then placing concrete to take any possible weight of loose ground. No longer is the trend toward a yeilding support, such as timber. New advances in concrete design make it possible for concrete to be transported as far as one mile in pipe lines. Possibly with further technical advances in design and placement concrete will be used entirely for all mine support.
FOOTNOTES


4. Taylor, F. W., Thompson, S. E., Concrete Plain and Reinforced, New York, 1917, p. 27.


8. Master Builders, "Pozzolith", Cleveland, Ohio, p. 15.


11. Ibid p. 87.

FOOTNOTES (cont.)


Calcium Chloride Institute, Calcium Chloride in Concrete, Washington D. C., February, 1954, pp. 1-29.


Master Builders, Pozzolith, Cleveland, p. 15.


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Taylor, F. W.; Thompson, S. E., Concrete Plain and Reinforced, New York, Wiley and Sons, 1917, p. 27.

APPENDIX
Fig. 1. Acceptable Fine Aggregate Before and After Separation by Sieves.


Fig. 2. Relation of Compressive Strength to Water Content.

Fig. 3. Comparison of Calcium Chloride Concrete with Plain Concrete.

Source: Calcium Chloride Institute, Calcium Chloride in Concrete, p. 6.
Fig. 4. Early Flexural Strength Gains Caused by Calcium Chloride.

Source: Calcium Chloride Institute, Calcium Chloride in Concrete, p. 7.
Fig. 5. Increase in Early and Ultimate Strength of Calcium Chloride Concrete.

Source: Calcium Chloride Institute, Calcium Chloride in Concrete, p. 9.
Fig. 6. Comparison of Calcium Chloride Concrete and Plain Concrete with Respect to Water Loss During Setting.

Source: Calcium Chloride Institute, Calcium Chloride in Concrete, p. 10.
Fig. 7. Workability and Density of Calcium Chloride Concrete Compared with Plain Concrete.

Source: Calcium Chloride Institute, *Calcium Chloride in Concrete*, p. 11.
Fig. 8. Pneumatic Placer Underground.

Fig. 9. Guniting Underground.

Fig. 10. Pumpcrete Machine and Valve Operation.

Source: Chain Belt Company, Pumpcrete Practice, p; 1.
Fig. 11. Standard Straight Sections and Elbows Used in Pipeline Concreting.

Fig. 12. Burlap Go-devil Used in Pneumatic Placing.

Source: Chain Belt Company, Pumpcrete Practice, p. 87.
Fig. 13. Concrete Batching Plant at Mather "B" Shaft.

A wooden wedge is driven in a slot in the pipe to prevent back-flow of concrete after pouring is completed.

Concrete forms are constructed of 1x8-in. and 4x6-in. timber. Rock wall serves as outside form except for ventilation doors.

Fig. 14. Wooden Concrete Forms.

Fig. 15. Hydraulically Operated Steel Forms.


Fig. 16. Steel Forms for Shaft Concreting.

Fig. 17. Steel Forms Underground.

Fig. 18. Installation of Reinforcing Steel in a Shaft.

Fig. 19. Water Ring in a Concreted Shaft.

Fig. 20. Pipeline Concreting in a Shaft.

Source: Chain Belt Company, *Pumpcrete Practice*, p. 43.