REMOTE SHOTCRETE LINING OF RAISED SHAFTS

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ABSTRACT

A raised-shaft lining system has been developed through a Bureau of Mines contract, "Development of Raise Boring/Shotcrete Support System" (Contract HO252003), awarded to Foster-Miller Associates, Inc.*, Waltham, Mass., working in conjunction with Peabody Coal Company. The system is specified to operate in raise-bored shafts 9 to 12 feet in diameter, be operated and monitored from the surface, place linings 2 to 6 inches thick, be operable to 1,000 feet deep and place linings at rates of up to 30 feet per hour. The operator controls the system based on feedback from two television cameras, a downshaft microphone and a thickness sensor. The system was demonstrated by lining a 12-foot-diameter, 168-foot-deep raise-bored shaft at Peabody Coal Company's Star mine near Madisonville, KY. The 5- to 6-inch-thick lining was placed in 21-1/2 hours of run time during 7 days. The system has been demonstrated to be feasible, under actual field conditions, in providing a safe and economic method of lining raise-bored shafts.

* Mention of specific companies or trade names is made for information only and does not imply endorsement by the Bureau of Mines.
INTRODUCTION

As part of its program to reduce the time, cost, and safety hazards associated with mine development, the Bureau of Mines funded Foster-Miller Associates, of Waltham, Mass., to develop the equipment to remotely line a raise-bored shaft with shotcrete. Specifications for this system included the following capabilities:

1. Complete remote control of nozzle,
2. Lining thickness of from 2 to 6 inches,
3. Lining rates of up to 30 feet per hour,
4. Lining of shaft diameters from 9 to 12 feet,
5. Operable depths to 1,000 feet,
6. Video monitoring system,
7. Thickness gage to measure thickness of placed material,

The goal was not to advance the state-of-the-art of shotcrete placement, but rather to provide a remotely controlled, partially automated system to apply good quality shotcrete to a raised shaft.

The system was developed around the dry process for a number of reasons, all related to the potentially long downhole pumping distance.

The dry process--

1. Permits addition of accelerator at the nozzle,
2. Avoids handling of 1,000 feet of wet concrete,
3. Minimizes line plugging,
4. Allows a lower water-cement ratio,
and 5. Reduces hydration during transport time.
Overall System Description

The complete shotcrete lining system is presented in figure 1. It may be conveniently divided into downhole and surface subsystems for purposes of discussion.

The downhole subsystem includes a modular, four section stage assembly that is 24 feet high, supported by a winch deployed wire rope, and guided in the raise by 12 wheels with pneumatic tires and torsion-bar suspension systems. The stage supports the rotary nozzle assembly and locates it on the shaft centerline. An artist's conception of the stage assembly is presented in figure 2. A photograph of the stage, with three sections assembled, is shown in figure 3.

Mounted from the rotary nozzle framework is a closed circuit television (TV) camera that continuously monitors the application of shotcrete and provides the feedback required to evaluate and control lining quality. A second closed circuit TV camera is fixed to the stage above the nozzle assembly facing downward to provide an overview of nozzle operation. A microphone-speaker system provides acoustic feedback as well. Mounted to the rear of the rotating nozzle framework is a tactile thickness sensor that continuously measures the thickness of the applied shotcrete layer. A photograph of the rotary nozzle assembly with the TV camera mounted in place is presented in figure 4.

The entire stage assembly is supported by a wire rope deployed from a winch at the surface. The winch control the rate at which the system is lowered during shotcrete application. With the nozzle rotating and descending at a constant rate, and the shotcrete flowing at
FIGURE 1. - Shotcrete Lining System
FIGURE 2. - Rotary Nozzle and Stage Assembly
FIGURE 3. - Surface Equipment and Stage

FIGURE 4. - Rotary Nozzle Assembly
a constant rate, the lining is applied in a helical pattern with predictable, uniform thickness. To vary the thickness, the rate of descent or the rate of shotcrete flow can be adjusted.

The dry mix shotcrete is delivered downward to the rotary nozzle through steel pipe. Water is added at the nozzle at a rate controlled by the system operator.

The system is controlled by the surface subsystems. From an enclosed cab located next to the winch enclosure, the operator controls the system based on feedback from the thickness sensor, two TV cameras (figs. 5-6) and a microphone. The video systems also provide a preview of conditions in the shaft—sloughed areas, water bearing zones, etc.—prior to the lining operation. Based on shaft conditions and the quality and thickness of the shotcrete applied, the operator may control—

1. Rate of descent,
2. Rate of rotation,
3. Direction of rotation,
4. Attitude of nozzle relative to wall,
5. Rate of shotcrete flow,
6. Rate of accelerator flow,
7. Rate of water flow.

The following aboveground equipment is required for system operation:

1. A Concrete Mobile* to proportion and mix the sand, aggregate and cement, and deliver the mix to the shotcrete machine at the desired rate.

* Manufactured by National Concrete Machinery Company, Division of IRL Daffin Associates, Lancaster, PA.
FIGURE 5. - Nozzle Television Monitor

FIGURE 6. - Stage Television Monitor
2. A shotcrete machine to meter and inject shotcrete mix into the conveying air line. The shotcrete machine has been fully instrumented with flow meters and pressure gages on both top and bottom air. A vibrating screen has also been added to eliminate oversize aggregate.

3. Shotcrete hose to convey shotcrete to the vertical steel pipe that connects to the rotary nozzle.

4. Water supply tank, booster pump and hose to provide water to the nozzle.

5. A variable-speed, positive-displacement pump for metering liquid accelerator. A dry additive feeder is optional.

6. Electrical cable reel and water hose reel.

7. A headsheave supported above the shaft by a guyed pillar and beam structure as shown in figure 1.

8. A winch and drum to spool the wire rope that supports the stage and nozzle assembly. The winch is an electrohydraulic unit with two drive systems—one for applying the shotcrete, and the other for maneuvering the stage.

9. Control console and cabin to enclose the console and operator. From the cabin, the operator has an unobstructed view of the shaft collar, the headsheave and the shotcrete machine and operator, as well as personnel working around the shaft. From the cabin, the operator has voice communication with the shotcrete machine operator.

Operation of the entire system during the lining of the shaft requires only three trained people—the system operator, the shotcrete machine operator and the Concrete Mobile operator. One additional person or the shotcrete machine operator is required at intervals of 20 feet to attach additional lengths of shotcrete pipe.
Critical goals of the remote lining system are (1) rapid erection with standard field equipment and (2) rapid lining capability. Meeting these goals can minimize the time a shaft is open and unsupported, and reduce the associated degradation of the shaft bore from weathering and stress redistribution in the rock.

The complete lining system weighs about 50,000 pounds and is transportable on two standard flatbed trailers. Offloading the components, assembly and erection requires a crane with a 30-foot boom. The heaviest single item is the winch package, which weighs approximately 9 tons with pallet and housing.

A 20- by 30-foot concrete pad for a 12-foot diameter shaft is usually centered on the shaft. The system can be assembled by a crew of four men in three working shifts.

Prior to the actual lining operation, the stage is lowered the full length of the shaft to inspect for general condition, sloughing or water-bearing areas. Locations of critical areas are recorded and a lining plan determined. These critical areas may be consolidated with a thin layer of shotcrete before the complete liner is applied.

The actual lining operation is completed in 20-foot increments. The section is inspected with the TV camera immediately prior to lining by tramming the stage through the 20 feet with the nozzle assembly rotating. With hoses attached and nozzle water and air on, the stage is cycled again to prepare the shaft walls.
REMOTE LINING

The stage is then returned to the top of the length to be lined with the nozzle rotating at the desired rate, material is added, and the flows are adjusted. Nozzle descent is begun at the rate required for the lining thickness desired.

The operator adjusts the water-flow and stage-descent rates as indicated by the TV monitors and the thickness sensor, respectively. When the 20-foot section is lined, material, air and water are shut off, and the lined section is again inspected.

The semi-automatic operation described can be overridden manually if it is necessary to fill a sloughed area, reinforce a weak region or combat high water flows. Under manual operation, the operator controls rotary speed and position, azimuth position and stage-descent rate.

A work platform has been provided atop the stage to permit inspection of the shotcrete lining or the application of curing compounds if desired.

Field Demonstration

During September 1976, the remote lining system was demonstrated at Peabody Coal Company's Star mine in Graham County, KY. It was used to line an intake ventilation and escapeway shaft 168 feet deep and 12 feet in diameter. A nominal 6-inch-thick shotcrete lining was applied over the entire length of shaft.

All materials were stockpiled at the site and checked prior to start of the lining operation. The sand and aggregate were covered with tarps, and the cement was stored in a bulk transport with a self-contained pneumatic transfer system. A Concrete Mobile was used to feed the system. Water was stored on site in a 2,000-gallon tank.
The poured concrete collar for the shaft was 13 feet in diameter and extended down 12 feet to bedrock. A sloughed area extended back under the collar approximately 1-1/2 feet and down one side of the shaft about 6 feet as shown in figure 7. Prior to application of the final continuous lining, it was necessary to build this region out to the diameter of the raised shaft. This was done using the manual mode of system operation, in which the operator continuously adjusts the rotation rate and direction, azimuth angle and the stage-descent rate to place material where required. Feedback from an observer on the surface was desirable during this task. A photograph of the collar region during this "patching" is presented in figure 8.

After filling the irregular region in this manner, the system was returned to the top and the application of the final lining begun. Mechanical and electrical problems with the lining system, the air compressor and the leased Concrete Mobile limited the actual lining time to only 2-1/2 hours. During the first day, shotcrete was placed on 19 feet of shaft to an average thickness of approximately 4-1/2 inches.

Figure 9 indicates the progress made during subsequent days as the technique improved and equipment problems were eliminated. On the last day, in spite of delays for materials, a total of 41 feet of lining was placed to a full 5- to 6-inch thickness. In addition, unsatisfactory portions of the shaft were patched.

Several water-bearing zones were encountered in the shaft. The initial attempt was to place a full 6-inch thickness of shotcrete in these areas to test the capability of the system. This approach failed,
FIGURE 7. - Raise Bored Shaft Before Lining

FIGURE 8. - Shaft Collar During Lining
<table>
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<tr>
<th>Depth</th>
<th>Layer Description</th>
<th>Date</th>
<th>Time</th>
<th>Yards³/hr</th>
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<tr>
<td>20</td>
<td>Br Sandstone</td>
<td>9/15, 16, 17</td>
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<td>F.C. Lt. Shale</td>
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<tr>
<td>170</td>
<td>Coal 9</td>
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FIGURE 9. - Shotcrete Lining Progress
leaving large sloughed areas to be patched later. A much more satisfactory approach was suggested in part by Jim Crawford of Sansan, Inc.

1. The walls in the wet zones were sandblasted with dry material to remove the accumulated layer of latent material.

2. A 1-inch-thick flash coat with 4 pct accelerator was applied over the entire wet zone.

3. This was followed by a continuous layer of shotcrete to develop the full lining thickness.

The remaining water zones were successfully lined using this technique.

During the field operation, eight 6- by 12-inch test cylinders were poured using the material mix delivered by the Concrete Mobile. Following completion of shaft lining, 10 cores 5.6 inches in diameter and nominally 6 inches long were taken from 5 different depths in the shaft. The shotcrete mix contained 3/8 aggregate, 7 to 7-1/2 bags of cement and 3 pct liquid accelerator. Core strength at 8 days was between 3,150 and 4,390 psi, except for one taken from the two-pass lining in the lower water zone. That core failed at 2,030 psi, with failure occurring at the lamination between the 1-inch flash coating and the 5-inch final layer. A 28-day-old core from the same water zone failed at 4,390 psi. Strengths of the remaining 28-day-old cores ranged from 4,000 to 6,030 psi. The strengths of two 6- by 12-inch cylinders (28 days old) were in excess of 5,600 psi.

Material loss due to rebound was estimated at 25 pct. This was based on material flow from the Concrete Mobile and the measured thickness of the wall.
Conclusions

Remote lining raised shafts with shotcrete has been demonstrated to be feasible. Based on the results of the field demonstration, a conservative economic analysis shows that, for a 12-foot-diameter shaft and a 6-inch-thick lining, lining costs of $50/ft can be achieved with the remote system. Comparable costs for concrete linings poured in the conventional manner start at $65/ft.

Even more important than the potential reductions in lining cost are other advantages derived from high-speed lining. The system increases the rate at which raise-bored shafts can be lined by a factor of three. This means—

1. Improved equipment utilization,
2. Faster development,

and 3. Fewer lost raises due to collapse.

Current legislation in some States prohibits men from working in unsupported shafts. Remote systems for lining shafts provide safer working conditions. Assuming only a moderate increase in coal production, it is estimated that over the next 10 years 1,600 new shafts will be required. These considerations, coupled with its demonstrated practicability, all favor the remote shotcrete lining system.