DEVELOPMENT OF A CONCRETE PLACEMENT DEVICE FOR SUPPORT OF ABANDONED MINES[1]

Mackenzie Burnett[2], Dr. Tahar El-Korchi[3], and James M. Burnett[2]

Abstract: Burnett Associates, Inc. (BAI), under contract to the U.S. Bureau of Mines, has developed a reliable and cost effective method of remote placement of point support columns in abandoned mines through boreholes to provide local support, especially under surface structures in subsidence prone areas. The development of the system to remotely build a concrete support cylinder in an abandoned mine required the coordination of mechanical system and concrete design. The mechanical system was designed to remotely place concrete in a cylindrical shape. The concrete was designed to meet the requirements of low slump with high enough strength to resist the forces applied by the ground above the mine. The support cylinder is fabricated through an 8-inch borehole by pumping concrete through a second 4-in pipe inside the borehole. The 4-in pipe has a flexible trunk on the lower end that is bent from the surface when it is inside the mine void. When pumping starts, the 4-in pipe is rotated and a spiral of concrete is placed on the mine floor. Operation continues until the concrete seals at the roof. A normal weight concrete as recommended by ACI 211 having a maximum slump of 1-2 in, a maximum coarse aggregate size of 1/2 in, and a minimum compressive strength of 5,000 psi was used. Cylinders have been fabricated to roof heights of 6 ft. There does not appear to be a technical height limitation. The concrete cylinder can support up to 40×10^6 lbs when fully cured and filled with gravel, depending on cylinder diameter.

Additional Key Words: mine subsidence, cement, grout, roof support.

Introduction

An improved reliable and cost effective method of remote placement of point support columns is needed to provide local support in subsidence prone areas especially under surface structures. A novel mechanical device to place very low slump concrete in an annular ring so as to build a cylindrical wall from floor to roof remotely through a borehole has been developed. The void in the center of the cylinder is filled with dry gravel. The system design for placing concrete underground in a controlled fashion is presented.

The conventional method of concrete or grout placement through boreholes has been to pump or drop concrete by gravity into the mine and to create a conical plug or seal by controlling slump through the mix design. Typically these methods use a large amount of concrete to obtain a fairly small area of support in the mine. The system presented here constructs a circular wall of concrete 10 ft or more in diameter. After this cylindrical wall has been built and the concrete has cured, the volume in the center of the annular wall is filled with a material such as gravel. This concept offers the advantage of lower cost than an all grout column and has the potential of providing full contact with the roof. The system was tested and developed at the Subsidence Abatement Investigation Laboratory (SAIL) at the U.S. Bureau of Mines.

Concrete Placement System Description

The system concept is shown in figures 1 - 3. The design allows the remote placement of concrete from the

---

[1] Paper presented at the International Land Reclamation and Mine drainage Conference and the third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA,April 24-29, 1994

[2] Mackenzie Burnett, President, James M. Burnett, Project Engineer, Burnett Associates, Inc., Framingham, MA, USA.

[3] Dr. Tahar El-Korchi, Professor of Civil Engineering, Worcester Polytechnic Institute, Worcester, MA, USA

Proceedings America Society of Mining and Reclamation, 1994 pp 39-47
DOI: 10.21000/JASMR94040039

https://doi.org/10.21000/JASMR94040039

surface of a borehole to create an annular wall of concrete in the mine void. Figure 1 shows the system installed at SAIL with placement of concrete at the beginning of the process. A section of hose (trunk) is mounted to the bottom of the delivery pipe. This trunk is fitted with hardware that allows it to be controllably bent from the surface after it has come out of the bottom of the cased borehole as shown in figure 2. The elevation and degree of bending of the hose is controlled using the system support device on the surface. The trunk hardware has been designed so that it will bend through a 120 degree angle. It has hinges to resist the torsion load on the trunk and stops so that it cannot be over bent. The support device also rotates the delivery pipe and trunk so that a continuous spiral of concrete can be laid to produce a concrete cylindrical wall that makes contact with the roof of the mine. The concrete is placed at a rate of 10 ft^3/min. The pipe rotates at approximately 3 rpm. Following construction of the cylindrical concrete support, the center of the cylinder is filled with gravel as shown in figure 3. The mechanical design of each system element is discussed in the following section. The concrete design description follows this in the cylinder performance and concrete design consideration section.

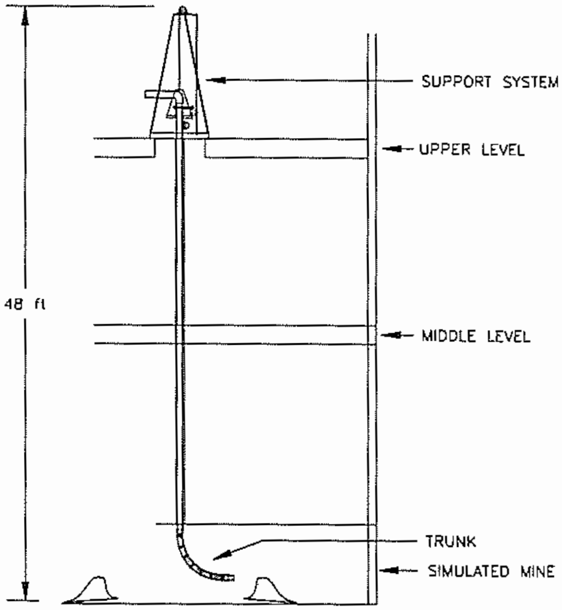

Figure 1. Controlled concrete placement system at SAIL.

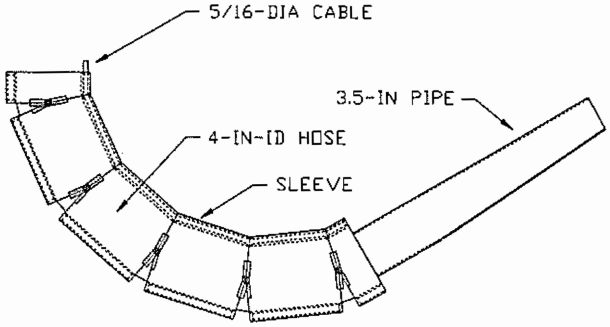

Figure 2. Trunk assembly.

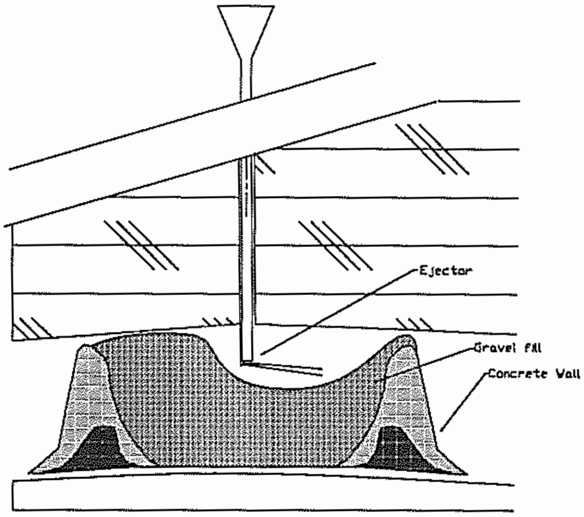

Figure 3. Filling the middle of the concrete annulus with backfill material.

Mechanical Design of Concrete Placement System

The following sections describe the mechanical design of the concrete placement system. The concrete placement system consists of a series of mechanical elements that allow remote placement of low slump concrete in a mine void through a borehole. The concrete placement system is made up of a support frame, a pipe installation system, a series of modified 4-in pipes and couplings, a rotation device, and a flexible trunk.

Support Frame. The support frame serves several functions. The frame system makes it possible to install the delivery pipe in sections as it is lowered into the borehole, and it provides a means to hold the pipe and trunk in the borehole. It contains the mechanism to rotate the pipe and trunk and to bend the trunk into the desired shape for concrete placement.

Figure 4 is a drawing of the complete system installed over a borehole. The frame was designed to be easily assembled on a job site. This allows an efficient means of transporting the system from site to site. The beams are pinned together at the ends and to

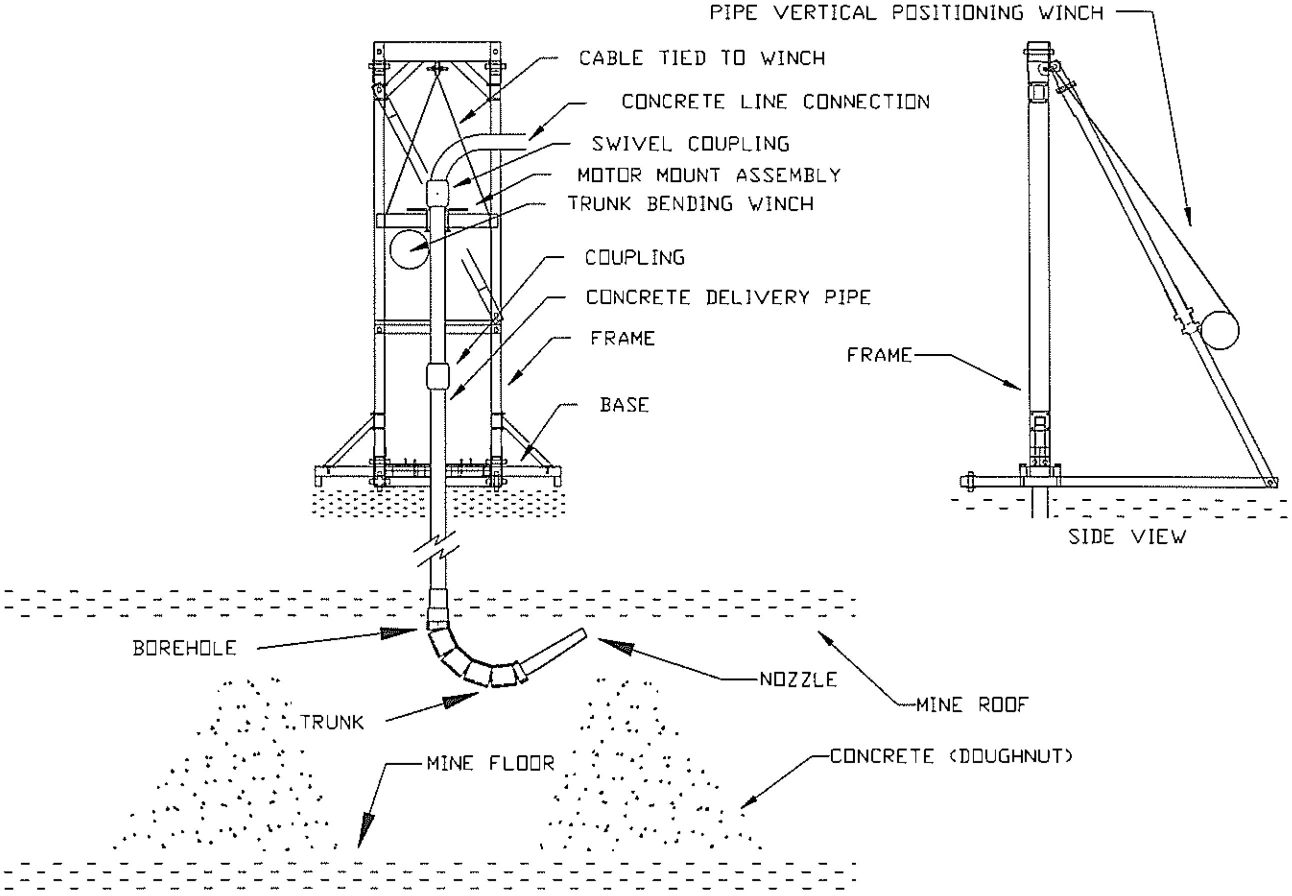

Figure 4. Concrete placement system.

brackets on the base of the frame. The motor mount assembly fits between the vertical frame members and is moved up and down by a winch and cable system. The frame is sized to handle 7-ft long pipe sections, but can be easily modified to accommodate longer sections.

Pipe Installation System. The pipe hoist fixture consists of cable mounts and a centered hole just large enough for the 4-in schedule 40 pipe to slip through. This allows the operator to slide the pipe into the hole and place a quick connect grooved coupling over the end of the pipe. After the coupling has been clamped on the pipe end, the winch is used to lift the pipe. In this manner the pipe is safely held in place while it is being connected to the pipe already in the borehole. The pipe hoist fixture is used only during pipe installation and removal and is removed from the headframe during concrete pumping. Sliding plates in the base of the frame close to support the pipe in the borehole while a section of pipe is added or removed.

Low Profile Pipe Clamps. Special, low-profile pipe clamps were designed for clearance in an 8-in borehole and to carry two cables alongside the pipe sections. One cable supplies the tension for trunk bending and the other will be used in the future for a borehole camera. The coupling is designed to grip a groove turned in the outside diameter of the pipe.

Pipe and Trunk Rotation System. This rotation system holds the motor and the pipe support bushing, and has slide grooves at the ends that ride ont the vertical members of the frame for torque resistance. The rotation system is used during operation only and is out of the way during pipe installation. It consists of a hydraulic motor, a section of 4-in pipe welded to a chain sprocket, a bronze bushing designed to fit over the pipe and slide in a fitting on the motor mount. The pipe winch, not shown, is clamped to the pipe just underneath the motor mount. This allows the cable that supports the bent trunk at the bottom of the borehole to rotate with the pipe assembly. A swivel pipe coupling is mounted to the top of the rotating feed pipe. The swivel coupling allows rotation of the trunk while pumping concrete. A pipe elbow is mounted on top of the coupling and connected to the hose from the concrete pumper.

Trunk Design. Figure 2 is a view of the trunk. The flexible hose (trunk) at the bottom of the concrete delivery pipe is the key to the system concept. It is obvious that the mechanism at the bottom of the pipe must fit through the 8-in borehole. The mechanical design of the trunk requires a means of bending the hose. The hose is bent after it is out of the borehole and in the mine void, by pulling on a cable attached to the end of the trunk with a hand winch. The required take-up is less than 5 inches. The trunk is made of several sleeves that are hinged together. These sleeves contain the tensioning cable, and the hinges resist torsion and bending forces applied to the end of the outlet nozzle.

The cable force required to bend the hose assembly for the 4-in hose is less than 2,400 lb. The end sleeves are designed with chamfered leading and trailing edges to insure that the assembly will go in and out of the borehole without hanging up. The borehole end of the hose has a standard high pressure fitting for a standard grooved 4-in pipe coupling. The outlet end of the hose has a specially designed nozzle that is directly connected to the hose. The nozzle tapers from 4-in pipe to a D-shaped outlet with a nominal diameter of 3.5 inches.

Concrete Design

Strength Considerations of Concrete Support. The Strength considerations for the concrete conical barrier will be twofold:

1. How soon after initial placement can the barrier be backfilled with gravel?
2. What is the overburden load that the concrete cylinder can support?

Initial backfilling time. The curing time before initial placement can begin is calculated by determining the active lateral earth pressure on the concrete wall from the gravel alone. The active earth pressure creates a tensile stress on the concrete cylinder. The concrete must develop enough tensile strength to hold the gravel before it can be filled. The cross-section of the conical concrete support is shown in figure 5. The lateral earth pressure induced by the gravel and the overburden surcharge due to subsidence will be modeled using the Rankine theory and calculated as follows.

$$P_a = \frac{1}{2} \gamma_s H \, K_a \frac{1}{144} \qquad (1)$$

Where:
P_a = lateral earth pressure lb/in^2
γ_s = gravel density lb/ft^3
H = height of wall
K_a = active lateral earth pressure coefficient ≈ 0.307 for $\phi = 32°$ (loose gravel)

With a gravel density of 100 lb/ft^3, and an internal wall height of 3.5 ft, the active lateral earth pressure from the gravel alone is only 0.4 psi.

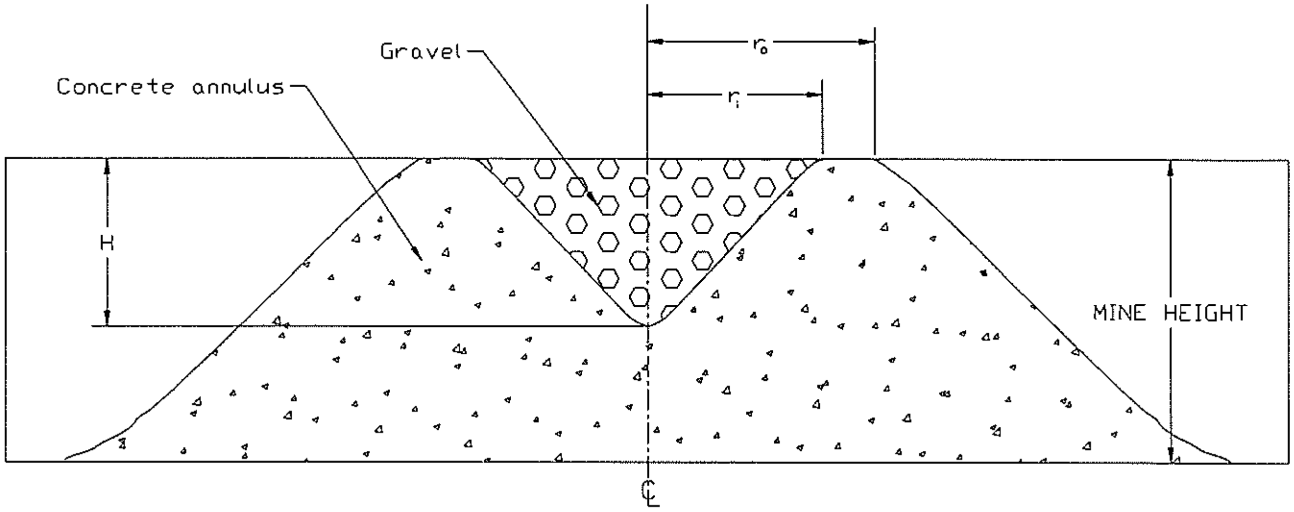

Figure 5. Cross-section of the conical concrete support with gravel.

The tensile strength of the concrete support during backfilling especially at the early ages of concrete curing is only 10% of its compressive strength. The conical concrete support may be modeled as a thick walled cylinder and the radial and tangential stress σ_r and σ_t respectfully are given as shown by equations 2 and 3. The maximum tensile and compressive stress occurs at $r = r_i$. The compressive stress due to the active lateral earth pressure is less than 1 psi and the tensile stress was calculated to be 1.6 psi. The concrete will easily achieve the required strength after one day of curing. Therefore, the conical concrete support may be backfilled as early as 1 day after the concrete has set.

$$\sigma_r = \frac{p_i r_i^2}{r_0^2 - r_i^2}\left(1 - \frac{r_0^2}{r^2}\right) \tag{2}$$

$$\sigma_t = \frac{p_i r_i^2}{r_0^2 - r_i^2}\left(1 + \frac{r_0^2}{r^2}\right) \tag{3}$$

where

p_i = the internal pressure simulated by the active earth pressure
r_0 = outside radius of cylinder top
r_i = inside radius of cylinder top

Overburden load. The total overburden load that the cylinder can support is the sum of load that can be supported by the gravel and the concrete cylinder wall. The concrete cylinder wall support capability is calculated by determining the area of the cylinder top and multiplying by the compressive strength of the cylinder as follows:

$$Load\ (lb)=C_s(\pi r_0^2-\pi r_i^2) \tag{4}$$

Where: C_s = compressive strength of concrete psi

The compressive strength of this concrete is between 4,000 and 5,000 psi. The inside radius at the top is 42 in, and the outside radius at the top is 54 in for a typical cylinder. Therefore, the load carrying capacity of this cylinder is between 14,500,000 and 18,100,000 lb.

The load carried by the gravel is limited by the tensile strength of the concrete since the gravel exerts pressure on the inside wall of the cylinder. Therefore the maximum load that the gravel can carry is determined by calculating the pressure placed on the inside wall of the cylinder due to the surcharge and active lateral pressures from the gravel. This load is calculated using the following equations:

$$P_{it}=P_a+P_sK_a \tag{5}$$

Where: P_{it} = total lateral internal pressure
P_s = surcharge pressure from overburden

At large values of P_s the active earth pressure P_a becomes insignificant. Equation 3 provides the tensile stress on the concrete as a function of total internal pressure. The maximum tensile strength of the concrete is expected to be 1/10th of its compressive strength. Therefore the maximum overburden pressure that the gravel in the structure will hold is 284 psi or 1,500,000 lb total load. The total load that the filled concrete cylinder will carry is the gravel load plus the cylinder load. The total is between 16,000,000 and 20,000,000 lb depending on the compressive strength of the concrete.

Concrete Mix Design

Concrete mix designs were conducted during the development at a concrete plant. Several trial mixes were conducted to obtain a low slump pumpable concrete using local materials. The trial mixes are presented in table 1. The final mix was selected based on stiffness (low slump) and potential flowability (sufficient amount of mortar) and pumpability. Several admixtures were used. A water reducer was used to maintain a low water-cement ratio and to allow for water adjustment at the job site. Experience has shown that fly ash added to the mix will increase slump loss due to the absorption of water, especially at high pumping pressures. Indications are that rounded aggregate will pump more easily than crushed stone, with a corresponding small loss in strength. The retarding admixture was used to prevent any premature setting of the concrete in the pipe system and to allow sufficient time for cleanup in the mine roof simulator. The final specification for the mix design is presented in table 2.

Testing

The point support system was tested at SAIL. The SAIL facility used for this portion of the program consists of a tower containing a simulated borehole that is 31-ft above ground level and connected to the quarry highwall by a catwalk. A 20-ft-wide by 4' to 6-ft-high simulated mine entry constructed of concrete block ribs and a corrugated steel roof is located at the bottom of the borehole. The headframe was placed on the platform at the top of the simulated borehole. A 100-ft concrete pipeline was laid along the catwalk to the pump location on the top of the highwall and two 10-ft-long flexible hoses were used to connect the pipeline to the elbow on the headframe. Ready-mix concrete was brought to the site and poured directly into the hopper on the pump. The concrete point support cylinders were constructed in the simulated mine entry at the base of the borehole.

Table 1. Concrete mix design experiments.

	Mix 1	Mix 2	Mix 3	Mix 4
Mix type	26 gal mix	28 gal mix	Repeat mix 2	Mix 3 (Air & Ret)
Cement lb/yd^3	611.6	611.6	611.6	611.6
Gravel No 67 lb/yd^3	1666	1666	1666	1666
Sand lb/yd^3	1771	1725.3	1628	1361
Water gal/ yd^3	159.3	175.5	216	235
Water reducer oz/100 lb Cement	2.8	2.8	2.8	2.8
Air admixture oz/100 lb Cement	0	0	0	0.8
Retarder admxture oz/100 lb Cement	0	0	0	1.4
Moisture content sand	2.7 %	2.7 %	2.7 %	2.7 %
Moisture Content Gravel	0.7%	0.7%	0.7%	0.7%
Initial Slump in	0	0	1/2	3¾
Final Slump in	-	-	-	2 ½
Air	-	-	-	6 1/2 %
Observations	Dry, crumbles not pumpable	Dry, crumbles not pumpable	- not pumpable	pumpable
Water added lb	6.5	3	-	-
New slump	2 in	2 in	-	-
Compressive Strength (29 day)				Cylinder A 5300 psi Cylinder B 5200 psi Cylinder C 5240 psi Avg Calc tensile Strength =510 psi Tensile

Construction of Concrete Mine Point Support Structures at SAIL.

During testing, there was an observer at the bottom of the borehole, an operator at the headframe location, and an operator at the pump location. Communication was achieved with radio headsets. In addition, a radio was located at the video recording location so the conversation could be recorded. The video camera was tripod mounted, and the entire run during pumping of each concrete cylinder was captured on video tape.

The test had three objectives. The first was to operate the concrete placement device and check its performance in terms of rotation control, concrete flow, hose performance and control, ease of assembly, and pipe installation. The second objective was to observe the slump and other properties of the concrete cylinder as a function of concrete mix and determine the compressive strength of the concrete. The third objective was to determine the operating parameters required to form a seal to the roof of the simulated mine. A total of six concrete cylinders have been constructed. The concrete mix design was selected based on the initial mix design experiments conducted at the concrete plant. The results of the initial mix designs were shown in table 1 and the final specifications are listed in table 2.

Equipment Setup and Operation. Equipment setup includes headframe setup, pipe installation, equipment operation, pipe removal and headframe takedown. During all phases of the operation, the equipment performed flawlessly. The initial Setup took 4 hours with three persons. With some experience and minor changes to the design the setup time could be reduced to 2-4 hours with two persons. The pipe installation was safe, straightforward, and easily accomplished with two persons in less than 1 hour. Takedown time was less than the setup. This translates into a turnaround of two days per concrete cylinder in the field with a new setup required for each borehole location. With some experience and close proximity between boreholes, it may be possible to fabricate one or two concrete support structures per day.

Equipment operation includes the pipe rotation system, the pipe raising and lowering mechanism, the pipeline swivel, and the hose bending system. The rotation of the pipeline was easily varied down to 3 rotations per minute. This could have been made lower by simply raising the pressure in the hydraulic line but there was no need for slower operation. The pipeline couplings prevented twisting of the line during rotation and held the cable as designed. The pipe raising and lowering mechanism provided the control of pipe height needed to make the cylinders. The pipeline swivel functioned well and did not become a source of leakage. The hose bending system including the sleeves, and the hose tension cable provided the control over hose bend radius that was required.

Table 2. Specifications for low slump pumpable concrete.

Max coarse aggregate in	0.5
Max slump in	2.5
Min slump in	1.75
Min mortar fraction ft^3/yd^3	17
Min cement factor bags..	6.5
Max air content %vol.....	5 % vol
Min 28 day compressive strength psi	4000

Note: Chemical and mineral admixtures may be used depending on specific site and construction conditions.

Results

The concrete placement system functioned well. The top of the cylinder sealed at the roof and the contact area width at the roof was controllable. After contact was made, continued pumping placed concrete on the outside of the cylinder and the width of the annular roof contact increased. When roof contact is made, the end of the nozzle begins to drag on the inside edge of the cylinder in the wet concrete. This increases the load on the hydraulic motor, and it either stalls or slows dramatically. This is a strong, foolproof indicator of roof contact. When the motor stalls, the operator simply boosts the pressure on the hydraulic power supply, and the hydraulic motor begins turning again. Concrete pumping continues until the desired roof contact as attained. Very accurate predictions of cylinder volume were attained. The concrete angle of repose for both the inner and outer cylinder walls is near 45°, and calculation of the concrete volume is a matter of geometry. Concrete mix design is very critical to the construction and final geometry of the mine support structure. A low slump pumpable concrete is essential. A stiff concrete is essential to minimize slumping of the concrete during the construction process. This reduces the volume of concrete required for a given height and final roof contact area. However, as was observed in the field, slump determines pumpability, with lower slump mixes being much easier to pump. The difficulty is attaining the lowest slump while maintaining a pumpable concrete. Continuous adjustments may be needed at the construction site for desirable concrete properties. Table 2 includes the starting point for mix design recommendations for a low slump pumpable concrete. Adjustment to the mix design may be required depending on changes in material and climate conditions.

Conclusions

The cylindrical concrete point support system adds a useful tool to the arsenal of the subsidence abatement official. It appears to be particularly well suited to the abatement of beam subsidence as described by Craft[1]. In areas where the floor of the mine is the primary cause of the subsidence, this point support approach offers a useful tool since the compressive stress on the floor will be at least 4 times lower than the compressive stress on the roof due to the cone shape of the cylinder. The concrete cylinder will provide a support capable of carrying over 22,000 tons using only 28 yd^3 of concrete in a 5-ft-high mine. The cylinder design can be adjusted for the conditions at a particular site to account for the load requirements of the site and the load carrying capacity of the roof and floor. This is accomplished be varying the diameter and annular roof contact thickness of the cylinder. The mechanical placement system was designed to be robust, to be easy to assemble, disassemble, and operate, and to accurately place concrete through a borehole. Testing at SAIL shows that the system works as designed. The concrete cylinder point support system testing was a success and should provide a useful subsidence abatement technique to AML programs, mine closure personnel, and locations requiring subsidence abatement.

Literature Cited

Craft, Jesse L. Ph.D. Classification of Mine Related-subsidence east of the Mississippi River, U.S.A. Office of Surface Mining Reclamation and Enforcement Pittsburgh, Pennsylvania