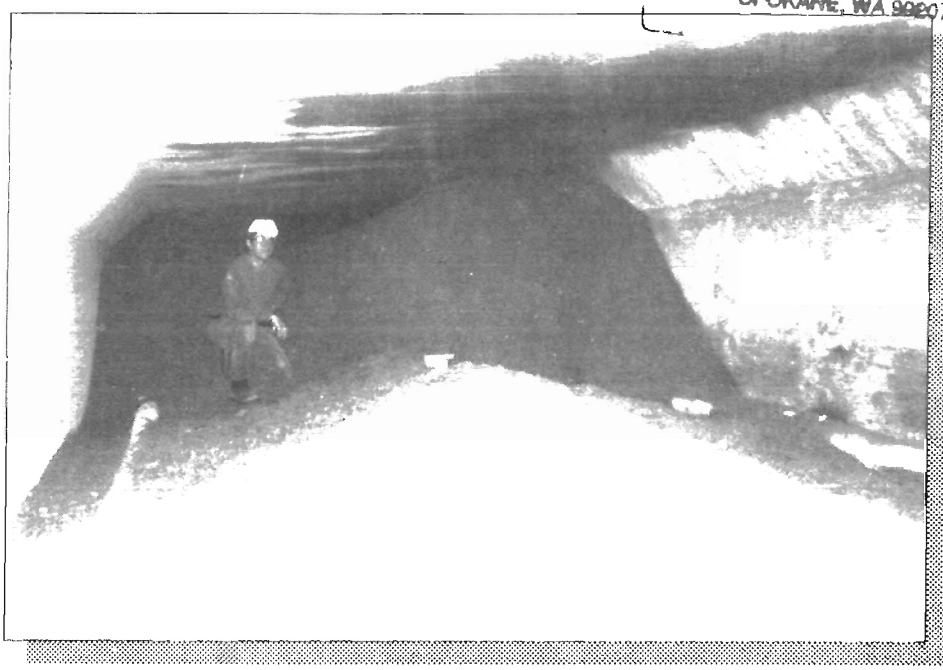
RI 9550

REPORT OF INVESTIGATIONS/1995



# Field Demonstration of Two Pneumatic Backfilling Technologies





UNITED STATES DEPARTMENT OF THE INTERIOR

UNITED STATES BUREAU OF MINES

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***Cover: Backfill material is deposited in an abandoned mine tunnel in a full-scale test of USBM pneumatic backfilling technologies. Backfilling mine voids prevents subsidence and the resulting damage to surface structures.***

Report of Investigations 9550

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By Robert C. Dyni, Mackenzie Burnett, and David Philbin

UNITED STATES DEPARTMENT OF THE INTERIOR
Bruce Babbitt, Secretary

BUREAU OF MINES
Rhea Lydia Graham, Director

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## UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Metric Units

| | | | |
|---|---|---|---|
| cm | centimeter | $m^3$ | cubic meter |
| dB | decibel | $m^3/min$ | cubic meter per minute |
| h | hour | t | metric ton |
| $kg/m^3$ | kilogram per cubic meter | t/d | metric ton per day |
| m | meter | t/h | metric ton per hour |
| m/s | meter per second | | |

U.S. Customary Units

| | | | |
|---|---|---|---|
| ft | foot | lf | linear foot |
| ft/s | foot per second | psig | pound (force) per square inch, gauge |
| $ft^3$ | cubic foot | st | short ton |
| $ft^3/min$ | cubic foot per minute | st/d | short ton per day |
| gal | gallon | st/h | short ton per hour |
| in | inch | $yd^2$ | square yard |
| $lbf/ft^3$ | pound (force) per cubic foot | $yd^3$ | cubic yard |

# FIELD DEMONSTRATION OF TWO PNEUMATIC BACKFILLING TECHNOLOGIES

By Robert C. Dyni,[1] Mackenzie Burnett,[2] and David Philbin[3]

## ABSTRACT

This U.S. Bureau of Mines (USBM) report summarizes a field demonstration of pneumatic backfilling technologies conducted at the abandoned Hillside Coal and Iron Slope in Vandling, PA. Researchers demonstrated two pneumatic backfilling technologies recently developed under the USBM's Abandoned Mine Reclamation Research Program, the Pneumatic Pipefeeder and the High-Efficiency Ejector. Both systems had previously been evaluated at the USBM's subsidence abatement investigation laboratory near Fairchance, PA.

The objective of the demonstration was to fill 100% of the abandoned tunnel with backfill stone to prevent further subsidence. The Pneumatic Pipefeeder was used for 21 days, at a rate of 63 to 124 t/d (69 to 136 st/d), to fill 88% of the tunnel. The High-Efficiency Ejector was used for 2 days, at a rate of 125 to 132 t/d (138 to 146 st/d) to fill the remaining 12% of the tunnel. The backfill placed by both systems was tightly compacted. The major problem encountered was wear on the polyethylene pipeline from the abrasion of the high-velocity backfill. The use of heavier steel pipe minimized the problem. A cost analysis for the entire project is given.

[1]Structural engineer, Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.
[2]President, Burnett Associates, Inc., Framingham, MA.
[3]Mining engineer, Office of Surface Mining, U.S. Department of the Interior, Wilkes-Barre, PA.

# INTRODUCTION

## BACKGROUND

Backfilling mine voids is the most common stabilization method used to abate subsidence and protect surface structures. The majority of the methods currently in use incorporate single or multiple boreholes to access abandoned underground workings; backfill material is either pneumatically or hydraulically injected into the abandoned workings through the boreholes to fill the mine openings and prevent or abate the collapse of overlying strata.

The U.S. Bureau of Mines (USBM), through the Abandoned Mine Reclamation Research Program, has conducted extensive research designed to advance the state-of-the-art of pneumatic backfilling systems (*1-4*).[4,5] The goals of this research are to develop technologies to mitigate subsidence, and to perform full-scale evaluations of methods and techniques, either currently available or under development, that are designed to mitigate subsidence. Pneumatic backfilling techniques have been extensively developed and tested under the USBM program; pneumatic stowing has been demonstrated to be an effective method for backfilling mine voids, but research has been needed to alleviate several operational and design problems associated with this technology.

Research under this program is conducted at the USBM's subsidence abatement investigation laboratory (SAIL). The SAIL provides a unique and flexible environment for evaluating the performance and effectiveness of a wide range of subsidence mitigation technologies. The SAIL is designed to simulate a borehole extending from the ground surface to an abandoned underground mine opening; the design is flexible, allowing for different borehole configurations as well as different mine geometries. Thus, any subsidence abatement technology that utilizes boreholes for the installation of artificial support can be effectively tested and evaluated at the SAIL (*5*).

Recent advancements in pneumatic backfilling technology research at the USBM have resulted in the development of two successful pneumatic backfilling devices. These devices were successfully tested at the SAIL, but had never been field tested at an abandoned mine land (AML) site. Without a full-scale demonstration of these devices at an actual AML site, the viability and durability of these systems could not be demonstrated and confirmed.

[4]Italic numbers in parentheses refer to items in the list of references at the end of this report.

[5]Research was also carried out under the following contracts:

Contract J0309012, Burnett Eng. Development of a High-Efficiency Ejector System, 1991.

Contract J0388015, L. C. Hanson Co. Design and Evaluation of a Remote Air-Jet Pneumatic Stowing System, 1990.

## VANDLING, PA, FIELD SITE

In October 1991, personnel from the Office of Surface Mining Reclamation and Enforcement (OSM), Wilkes-Barre, PA, field office, investigated a subsidence event that occurred in the surface of an undeveloped road in Vandling, Lackawanna County, PA. The subsidence event was the result of the collapse of a portion of a coal mine haulage tunnel, known as the Hillside Coal and Iron Slope. The tunnel was originally used to transport coal from a mine to a railroad siding in the early 1900's, and it is situated directly underneath several of Vandling's residential streets and crosses underneath a State highway. After a thorough review of the available information, as well as a detailed inspection of the condition of the tunnel, OSM personnel determined that the slope presented a potential hazard to the safety and welfare of the residents and vehicular and pedestrian traffic in the area.

OSM personnel contacted USBM researchers to offer the site as a field demonstration site for the USBM's pneumatic backfilling technologies. The USBM and OSM entered into an interagency agreement that allowed the USBM to demonstrate the two pneumatic devices and at the same time fulfilled OSM's responsibility to remediate the potentially dangerous conditions existing at the site.

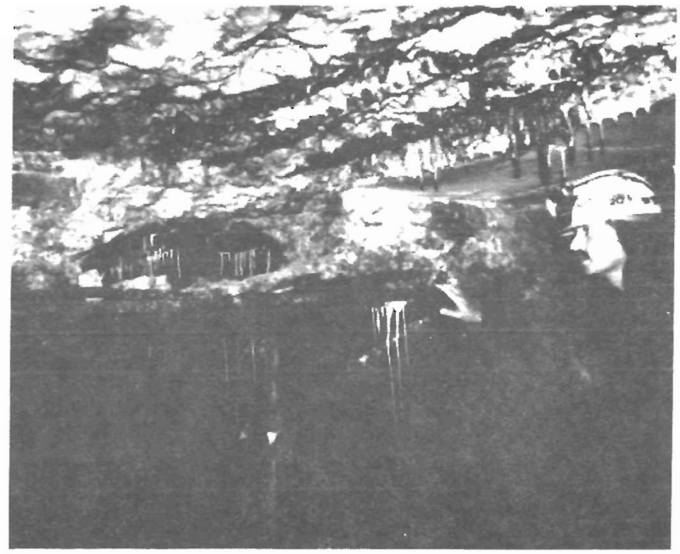
The tunnel was constructed presumably by the cut-and-cover method; a trench was likely cut into the ground, the tunnel was fabricated, and fill was then placed over the top of the tunnel to the original grade level. The roof, walls, and floor of the tunnel were fabricated of poured concrete with four layers of 2.5-cm (1-in) steel reinforcing bars embedded in the concrete for structural reinforcement. The only interior support in the tunnel is located at the point where the tunnel passes underneath State Highway 171. Here there are three concrete columns spaced 4.6 m (15 ft) apart and centered on the tunnel's longitudinal centerline (figure 1). These columns support a two-span concrete roof-support beam, designed to support the tunnel roof. At the time of construction a railroad line passed over the tunnel at this location, and it was feared that the weight of overlying trains could collapse the tunnel if no interior supports were provided. Figure 2 shows the deteriorated condition of the concrete support beam.

The tunnel was straight, through its entire length, and was sloped so that the upper portal was approximately 15 m (50 ft) higher than the lower portal. Figures 3 and 4 show the ground surface directly over the tunnel. The overall length of the tunnel was approximately 183 m (600 ft), the width was 4 m (14 ft), and the maximum floor-to-roof height was approximately 2.5 m (8 ft). Irregular deposits of silt on the floor of the tunnel throughout its length reduced the roof height in many places. The top of the tunnel at the upper elevation was approximately 0.3 to 0.6 m (1 to 2 ft) below grade level, while at the lower end of the tunnel the top of the tunnel was approximately 1.5 to 3.0 m (5 to 10 ft) below grade. Both tunnel portals were sealed; the lower portal was plugged with earthen material, and the upper portal was sealed with a concrete bulkhead previously constructed by OSM.

*Figure 1*

*One of three concrete columns in tunnel.*

*Figure 2*



*Deteriorated condition of tunnel support beam.*

*Figure 3*

*View of ground surface above tunnel, looking toward upper tunnel end. Upper tunnel end is at end of street near utility pole.*

*Figure 4*

*View of ground surface above tunnel, looking toward lower tunnel end. Lower tunnel end is at end of street near tree line.*

## PNEUMATIC BACKFILLING SYSTEMS TESTED

The two pneumatic backfilling systems developed and tested under the USBM's Abandoned Mine Reclamation Research Program were designed to provide an inexpensive and effective means of pneumatically placing backfill into an underground mine opening. Both systems were successfully tested in previous research at the SAIL. Complete descriptions on the development and testing of these two devices have previously been published (*1*).[6]

### PNEUMATIC PIPEFEEDER

The Pneumatic Pipefeeder was designed to inject backfill material up to 3.8 cm (1.5 in) in size through a 15-cm (6-in) diameter pipeline at rates up to 41 t/h (45 st/h). The overall design objective of this device was to overcome the problems associated with a similar backfilling device, the commercially available rotary airlock feeder (RALF). A RALF can inject backfill at high tonnage rates, but it is expensive and suffers from frequent wear and damage to its internal chambers and sealing plates. The Pneumatic Pipefeeder, on the other hand, has no moving parts, which eliminates the wear problems associated with the RALF.

The Pneumatic Pipefeeder was designed to transport backfill material through the 15-cm (6-in) diameter pipeline for lengths of up to 300 m (1,000 ft). Figure 5 shows the major components of the Pneumatic Pipefeeder assembly. This device was tested at the SAIL in 1989, where it successfully transported backfill material through a 26-m (85-ft) long, 15-cm (6-in) diameter pipeline. The maximum pipeline length through which the Pneumatic Pipefeeder could successfully transport backfill material was not determined during this testing.

Basically, the Pneumatic Pipefeeder utilizes a supersonic-velocity airstream to accelerate the backfill material to a high transport velocity. The intake hopper is used to feed the backfill material into the pipefeeder. The intake hopper was constructed of 0.6-cm (¼-in) steel plate and was bolted to the sweep. The intake hopper was

[6] Also covered in first contract report listed in footnote 5.

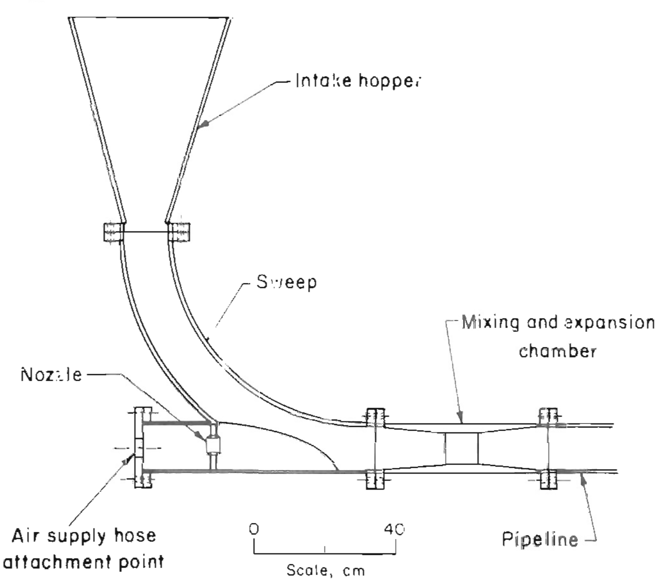
designed to accept backfill material from a conveyor belt or a vibratory feeder; by controlling the speed of the belt or feeder, the intake hopper can deliver the proper amount of backfill material to the Pneumatic Pipefeeder.

The sweep delivers the backfill material from the intake hopper to a position directly in front of the supersonic nozzle. This sweep was constructed of 15-cm (6-in) diameter, Schedule 40 steel pipe. As the backfill material passes through the sweep, it is reoriented from a vertical transport direction to a horizontal direction. The sweep was designed with a 0.6-m (2-ft) radius elbow to ensure that the backfill material traversed the sweep without plugging. A short-radius elbow could potentially cause plugging of the sweep, which would prohibit the flow of backfill material from the intake hopper. When the slow-moving backfill material traverses the sweep and passes in front of the supersonic airstream, it is accelerated by the high-velocity air from the supersonic nozzle, which is oriented directly down the pipeline.

The nozzle itself is a specially designed convergent-divergent nozzle that accelerates incoming 690-kPa (100-psig) air to over 488 m/s (1,600 ft/s). The supersonic-velocity air impinges directly on the backfill material, and by the principles of momentum exchange, the material is accelerated to over 30 m/s (100 ft/s). The air supplied to the nozzle for the tests at the SAIL was provided by two air compressors delivering 60 $m^3$/min (2,120 $ft^3$/min) at 690 kPa (100 psig).

The mixing and expansion chamber assists in thoroughly entraining the backfill material in the airstream and further accelerating the air-backfill mixture. This chamber is bolted onto the horizontal end of the sweep. The pipeline tested at the SAIL was made up of sections of 15-cm (6-in) diameter polyvinyl chloride pipe connected end-to-end with Victaulic couplings. The pipeline is connected to the mixing and expansion chamber with an adapter.

*Figure 5*



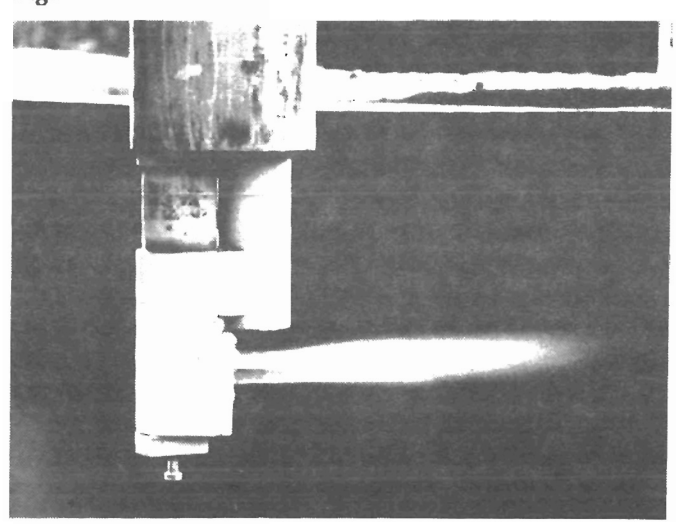

*Pneumatic Pipefeeder.*

## HIGH-EFFICIENCY EJECTOR

Unlike the Pneumatic Pipefeeder, which requires direct access to an underground mine opening so that the pipeline can be assembled, the High-Efficiency Ejector was designed to remotely backfill an underground mine opening through a 20-cm (8-in) diameter borehole. The High-Efficiency Ejector was designed to solve the high wear problems associated with earlier pneumatic borehole backfilling designs, which incorporated 90° elbows that redirected the flow of backfill material from a vertical direction to a horizontal direction. Figure 6 shows the major components of the High-Efficiency Ejector. Like the Pneumatic Pipefeeder, the High-Efficiency Ejector utilizes a supersonic airstream to accelerate the backfill material and redirect it horizontally. The High-Efficiency Ejector tested at the SAIL contained five supersonic nozzles.

The overall design of the High-Efficiency Ejector is straightforward. Basically, two 8.9-cm (3.5-in) diameter steel pipes supply air and the backfill material from the ground surface through the borehole and to the High-Efficiency Ejector. The five nozzles are situated directly below and behind the bottom of the backfill supply pipe, so that as the material passes in front of the nozzles, it is redirected and accelerated horizontally. At the top of the material supply pipe is an intake hopper identical in design to the intake hopper used for the Pneumatic Pipefeeder. The air supply pipe delivers 57 $m^3$/min (2,000 $ft^3$/min) air at 690 kPa (100 psig) to the five nozzles, and after passing

*Figure 6*



*High-Efficiency Ejector.*

through the nozzles, the air is accelerated to a velocity of approximately 488 m/s (1,600 ft/s).

### BACKFILL MATERIALS

Two sizes of quarried sandstone were used as backfill material at the Vandling site. The first stone used was 2.5-cm-minus (1-in-minus) stone, and the second stone was 0.6-cm-minus (¼-in-minus). Both sizes had an approximate material density of 1,600 kg/m³ (100 lbf/ft³). Previous testing of the two backfilling devices had not indicated how, if at all, performance would vary when backfilling different material sizes. Thus, the Vandling demonstration provided researchers with an ideal opportunity to compare the performance of both the Pneumatic Pipefeeder and the High-Efficiency Ejector when used to backfill with two different stone sizes.

## FIELD DEMONSTRATION

### REMEDIATION PLAN

The goal of the project at the Vandling site was to fill 100% of the abandoned coal mine haulage tunnel with backfill stone using both the Pneumatic Pipefeeder and the High-Efficiency Ejector. The tunnel was divided into five zones (figure 7); zones 1 through 3 were backfilled from the hole 1 location, and zones 4 and 5 were backfilled from hole 2. Zones 1, 2, and 4 were backfilled using the Pneumatic Pipefeeder, and zones 3 and 5 were filled using the High-Efficiency Ejector. The zones were sequentially backfilled in order from 1 to 5.

### SITE PREPARATION

#### Tunnel Access

Hole 1 was constructed by removing approximately 1.2 m (4 ft) of overburden overlying the roof of the tunnel with a backhoe, then removing a 1-m (3-ft) by 3-m (10-ft) portion of the concrete tunnel roof with a pneumatic hammer (figure 8). The hole was oriented so that it was centered over the roof centerline. The four mats of steel rebar were cut using an electric grinder. Hole 1 was located approximately 60 m (200 ft) up from the bottom end of the tunnel.

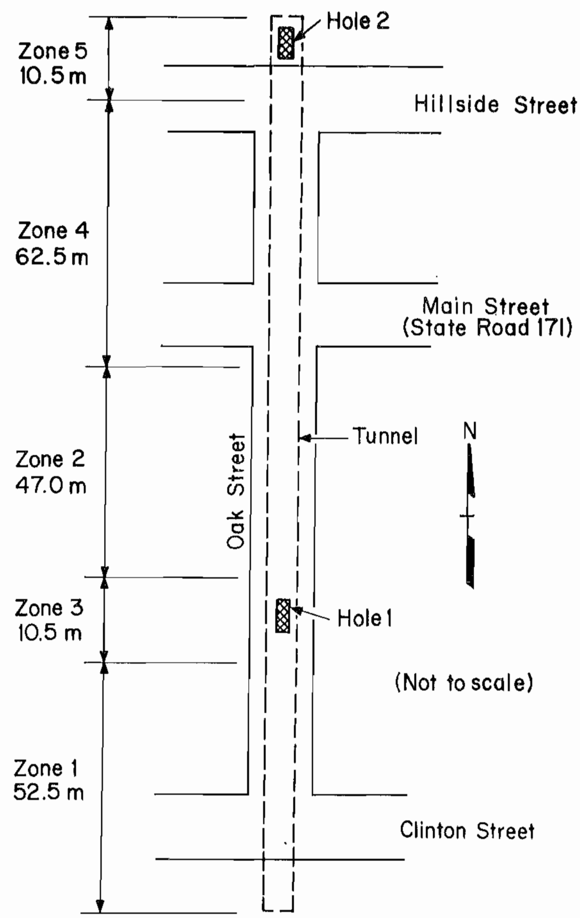
Hole 2 was opened in the same manner; the overburden depth above the tunnel roof at the hole 2 location was approximately 0.3 m (1 ft). The approximate dimensions of hole 2 were 1.2 m (4 ft) wide by 3 m (10 ft) long. Hole 2 was located in the center of the roof at the upper limit of the tunnel (figure 9).

#### Tunnel Survey

After the first hole (hole 2) was constructed, a mine survey was conducted. This survey was designed to assess the condition of the tunnel and to establish overall geometry. The survey consisted of length, width, and height measurements, coupled with visual assessments of the tunnel interior. From this survey, it was possible to accurately estimate the total amount of backfill material required to fill the tunnel, as well as assess the overall condition and present state of deterioration of the tunnel. The survey also provided information needed to determine where hole 1 was to be located.

Calculations from the survey revealed a total tunnel volume of approximately 1,360 m³ (48,000 ft³). Thus, based on the backfill material density of the 2.5-cm-minus (1-in-minus) and the 0.6-cm-minus (¼-in-minus) stone of

***Figure 7***

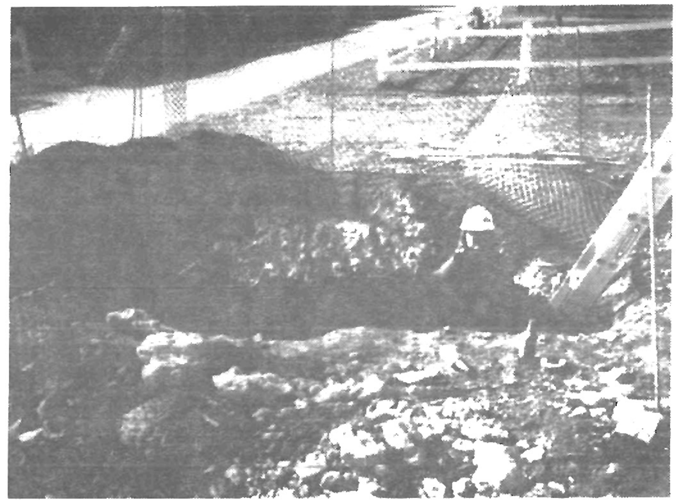



***Tunnel plan view.***

*Figure 8*

*Preparation of hole 1.*

*Figure 9*



*Hole 2.*

1,600 kg/m$^3$ (100 lbf/ft$^3$), approximately 2,176 t (2,400 st) of backfill would be required to completely fill the tunnel opening.

### Safety Considerations

Safety was a primary concern throughout the project. Thus, before personnel were allowed into the tunnel to conduct the survey, a safety inspector from the Mine Safety and Health Administration (MSHA) conducted an inspection of the tunnel's air quality. This was done to ensure that the tunnel had an adequate supply of oxygen and did not contain any toxic gases. The MSHA inspection found no oxygen deficiency or presence of other gases, and the tunnel was considered safe for access.

Holes 1 and 2, besides providing the two required access openings into the tunnel for remediation purposes, also served to provide a conduit for natural air circulation throughout the tunnel's length. This feature allowed the tunnel to be continuously ventilated, thereby continuously supplying fresh air to the underground environment.

Backfilling operations using the Pneumatic Pipefeeder and the High-Efficiency Ejector produce a significant amount of dust, so all personnel entering the tunnel to perform maintenance operations or progress inspections used twin-cartridge respirators to protect themselves from any respirable suspended dust particles. Additionally, the two air compressors used on the project had placards warning of the possibility of the air supply being contaminated with airborne oil mist generated from the compressor pumps. The respirator cartridges were also capable of filtering out this hazard. As an additional safety consideration, no research personnel were allowed into the tunnel until the natural ventilation provided by holes 1 and 2 was able to clear most of the visible dust from the tunnel opening, and an air-quality survey was conducted by OSM (figure 10).

The structural integrity of the tunnel, as found by the tunnel survey, was suitable for safe access. Although the tunnel roof and walls had deteriorated in places to the point where the reinforcing bars were exposed, danger from immediate collapse was considered minimal. No supplemental roof support was utilized during the remediation process.

## BACKFILLING OPERATIONS, HOLE 1

### Pneumatic Pipefeeder, Zone 1

Backfilling operations began at hole 1 with the Pneumatic Pipefeeder. The Pneumatic Pipefeeder was placed on top of the tunnel roof at the edge of hole 1, and 46 m (150 ft) of 3-m (10-ft) long, 15-cm (6-in) diameter high-density polyethylene pipe was placed from the Pneumatic Pipefeeder down toward the lower end of the tunnel (figure 11). This resulted in approximately 15 m (50 ft) of separation between the discharge end of the pipeline and the end of the tunnel. The pipe sections were connected with two-piece Victaulic couplings.

High-density polyethylene pipe was chosen as the pipeline material because of its light weight and favorable wear characteristics. The light weight of each section of pipe allowed two workers to easily transport and connect the pipe sections within the tunnel. The sections of pipe were installed in the tunnel so that there were no sharp bends along the length of the pipeline. This was accomplished by using wood crib blocks to elevate portions of the pipeline and achieve a gradual curve throughout its length. The

*Figure 10*

*Air-quality testing in tunnel interior.*

overall shape of the pipeline was such that the discharge end was approximately 1.2 m (4 ft) off the tunnel floor and directed toward the roof. With the crib blocks, the pipeline was allowed to maintain a gently curving shape with no sharp angles that might lead to premature wear of the pipeline.

On the surface, the support equipment required for operating the Pneumatic Pipefeeder was assembled and readied for operation. Two diesel-powered air compressors were used to supply the air to the Pneumatic Pipefeeder; one compressor was rated at 35 $m^3$/min (1,250 $ft^3$/min) at 690 kPa (100 psig), and the other was rated at 21 $m^3$/min (750 $ft^3$/min) at 690 kPa (100 psig). The output hoses of the two compressors were joined with an adapter (figure 12), and a single hose was connected from the adapter to the Pneumatic Pipefeeder.

A gasoline-powered portable conveyor with an integral 4-$m^3$ (5-$yd^3$) hopper was placed over the Pneumatic Pipefeeder's conical hopper (figure 13) to feed backfill into the Pneumatic Pipefeeder. The conveyor's belt velocity was adjustable, so that the amount of backfill stone entering the Pneumatic Pipefeeder was controllable. The hopper for the conveyor was loaded and maintained with backfill stone with a front-end loader. The stockpile of backfill stone was maintained near the conveyor unit.

Approximately 1½ working days were used to excavate holes 1 and 2, to perform the safety and inspection surveys, and to assemble and test the Pneumatic Pipefeeder and all support equipment. Backfilling of zone 1 with 2.5-cm-minus (1-in-minus) stone began in earnest on the third working day. The procedure was to backfill the tunnel until the backfill pile progressed to within approximately 3 m (10 ft) of the discharge end of the pipeline; when the backfill pile reached this point, three or more sections of pipe would be removed, and the process started over again. In this way, the backfill pile would never be more than 9 to 15 m (30 to 50 ft) away from the discharge end of the pipeline.

The Pneumatic Pipefeeder was shut down several times per working day during the first several days of operation to allow inspection of the progress of the backfill pile in the tunnel. It became immediately apparent that the backfill was being discharged in a tightly focused spray into the tunnel, which resulted in a pile of backfill that was smaller than the width of the tunnel opening (figure 14). Thus, for each section of pipeline remaining, the pipeline was aimed first at the left half of the opening until the pile reached approximately 3 m (10 ft) of the pipeline, then the pipeline was shifted to the right half of the opening. These pipeline shifts took place after the Pneumatic Pipefeeder was shut down, and the tunnel was adequately ventilated.

It was apparent after the third day of backfilling operations that the high-density polyethylene pipeline was not performing satisfactorily. The pipe was wearing severely at all outside curves along the length of the pipeline. The researchers thus decided to install the Pneumatic

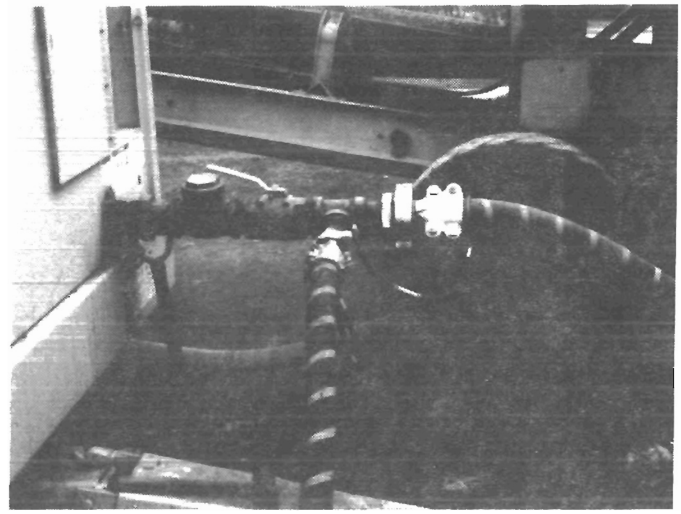
*Figure 11*

*Installation of Pneumatic Pipefeeder in hole 1.*

Pipefeeder directly on the tunnel floor (figure 15) to minimize the bends in the pipeline that were necessary to pass through hole 1. After four more working days, it was evident that even though the bends were minimized, the high-density polyethylene material could not withstand the abrasion exerted by the backfill. The researchers then decided to replace the high-density polyethylene pipe with Schedule 10 steel pipe. Although 15-cm (6-in) nominal diameter Schedule 10 steel pipe is approximately 200% heavier per unit length than the high-density polyethylene, its resistance to abrasion is greater. To minimize the difficulties in handling the steel pipe, 2-m (7-ft) sections were obtained. Backfilling the remainder of zone 1 was completed with the Schedule 10 steel pipeline and with the Pneumatic Pipefeeder resting on the floor of the tunnel directly below hole 1.

Zone 1 was completely backfilled with 2.5-cm-minus (1-in-minus) stone in approximately 10 working days. It

*Figure 12*



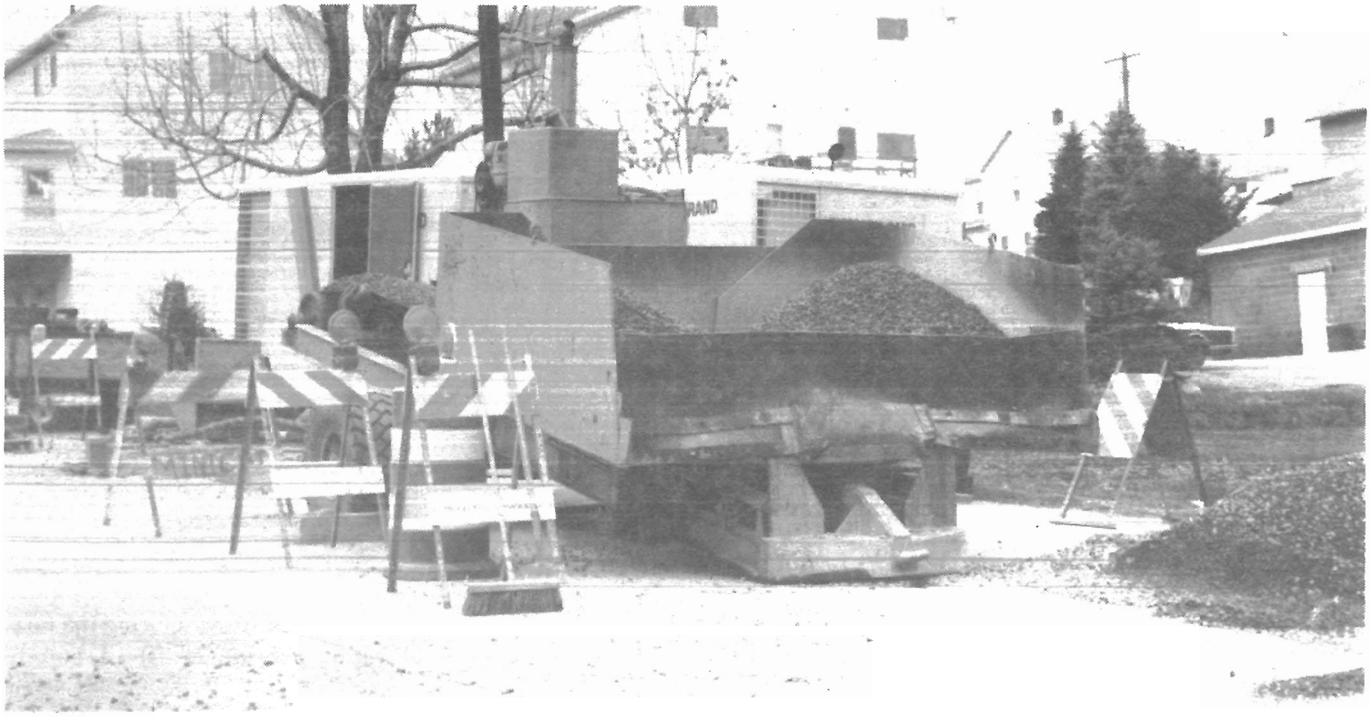
*Connection of two air compressors.*

took approximately 628 t (692 st) of stone to bring the face of the backfill pile to within 7.5 m (25 ft) of hole 1 (table 1).

**Table 1.—Performance results for Pneumatic Pipefeeder**

| | | |
|---|---|---|
| ZONE 1 | | |
| Maximum stone size, cm (in) | 2.5 | (1) |
| Number of working days | 10 | |
| Per day: | | |
| Backfill, t (st) | 63 | (69) |
| Face advance, m (ft) | 5 | (18) |
| Percent of tunnel filled | 3 | |
| Total: | | |
| Backfill, t (st) | 628 | (692) |
| Face advance, m (ft) | 53 | (175) |
| Percent of tunnel filled | 29 | |
| ZONE 2 | | |
| Maximum stone size, cm (in) | 2.5 | (1) |
| Number of working days | 5 | |
| Per day: | | |
| Backfill, t (st) | 110 | (121) |
| Face advance, m (ft) | 9 | (30) |
| Percent of tunnel filled | 5 | |
| Total: | | |
| Backfill, t (st) | 549 | (605) |
| Face advance, m (ft) | 46 | (150) |
| Percent of tunnel filled | 25 | |
| ZONE 4 | | |
| Maximum stone size, cm (in) | 0.6 | (0.25) |
| Number of working days | 6 | |
| Per day: | | |
| Backfill, t (st) | 124 | (136) |
| Face advance, m (ft) | 10 | (34) |
| Percent of tunnel filled | 6 | |
| Total: | | |
| Backfill, t (st) | 741 | (817) |
| Face advance, m (ft) | 62 | (205) |
| Percent of tunnel filled | 34 | |

*Figure 13*

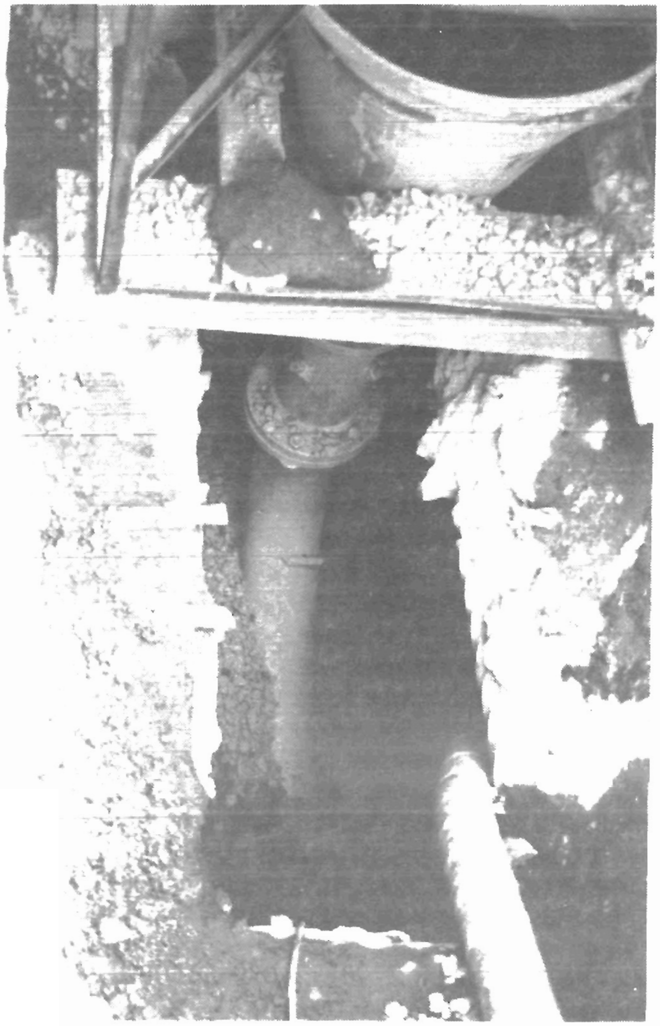


*Portable hopper-conveyor.*

*Figure 14*

*Deposition of backfill in tunnel interior.*

*Figure 15*



*Installation of Pneumatic Pipefeeder on tunnel floor.*

## Pneumatic Pipefeeder, Zone 2

Upon completion of zone 1 backfilling, the Pneumatic Pipefeeder was rotated 180° so that it was aimed up toward the upper end of the tunnel. A 32-m (105-ft) long pipeline consisting of 15 sections of 2-m (7-ft) long Schedule 10 pipe was assembled with Victaulic couplings, again using wood crib blocks to provide a gentle curve to the pipeline and raise the discharge end approximately 1.2 m (4 ft) off the tunnel floor. Using the same procedures utilized for zone 1 backfilling, zone 2 was completely backfilled in 5 working days, and it required approximately 549 t (605 st) of 2.5-cm-minus (1-in-minus) stone (table 1). The face of the backfill pile was approximately 3 m (10 ft) updip from hole 1.

## High-Efficiency Ejector, Zone 3

Upon completion of backfilling zones 1 and 2 with the Pneumatic Pipefeeder, approximately 10.5 m (35 ft) of tunnel remained to be backfilled at the hole 1 location. This length of tunnel was backfilled with the High-Efficiency Ejector.

The support equipment required for the High-Efficiency Ejector was identical to that required for the Pneumatic Pipefeeder. The High-Efficiency Ejector was placed in the opening so that the backfill would be redirected by the nozzles immediately below the tunnel roof. Since the High-Efficiency Ejector was designed for borehole applications, a framework was fabricated to position it in the middle of hole 1. At this point, the backfill stone size was changed to 0.6-cm-minus (¼-in-minus), and which was used throughout the remainder of the project.

The High-Efficiency Ejector was first aimed down toward the lower backfill face created in the zone 1 backfilling operation. The High-Efficiency Ejector was periodically rotated to ensure that the backfill was being evenly distributed over the entire width of the tunnel opening. When the face of the backfill pile was within 1.5 m (5 ft) of the High-Efficiency Ejector, the High-Efficiency Ejector was rotated 180° and aimed toward the upper backfill face created in the zone 2 backfilling operation. Again, the High-Efficiency Ejector was periodically rotated to ensure complete filling of the opening.

It took 1 working day and approximately 132 t (146 st) of 0.6-cm-minus (¼-in-minus) stone to completely fill the 10.5-m (35-ft) long gap between the zones 1 and 2 backfill piles (table 2).

**Table 2.—Performance results for High-Efficiency Ejector**

| | | |
|---|---|---|
| ZONE 3 | | |
| Maximum stone size, cm (in) | 0.6 | (0.25) |
| Number of working days | 1 | |
| Per day: | | |
| Backfill, t (st) | 132 | (146) |
| Face advance, m (ft) | 11 | (35) |
| Percent of tunnel filled | 6 | |
| ZONE 5 | | |
| Maximum stone size, cm (in) | 0.6 | (0.25) |
| Number of working days | 1 | |
| Per day: | | |
| Backfill, t (st) | 125 | (138) |
| Face advance, m (ft) | 11 | (35) |
| Percent of tunnel filled | 6 | |

## BACKFILLING OPERATIONS, HOLE 2

### Pneumatic Pipefeeder, Zone 4

When the backfilling of zones 1 through 3 was completed, all equipment and the backfill stockpile were transferred up to the hole 2 location at the top end of the tunnel. At this point in the project, the tunnel had been completely filled from the lower end to approximately 110 m (360 ft) from the lower end. Thus, the backfill face was approximately 73 m (240 ft) downdip from hole 2.

The Pneumatic Pipefeeder was used to backfill zone 4 of the tunnel. It was lowered through hole 2 and assembled on the floor of the tunnel. A 64-m (210-ft) long pipeline was then constructed. Inspection of the Schedule 10 pipe revealed several localized areas of severe wear, so researchers decided to use several sections of thicker walled Schedule 40 steel pipe in conjunction with the Schedule 10 pipe. The first 15 m (50 ft) of the pipeline, beginning at the Pneumatic Pipefeeder, was constructed with Schedule 40 pipe, and the remainder was Schedule 10. In this way, the sections of pipe remaining on the pipeline the longest as the backfill pile progressed up the tunnel would be the thicker walled Schedule 40. The conveyor, air compressors, and material stockpile were readied as they had been for hole 1 operations.

It took 6 working days and approximately 741 t (817 st) of 0.6-cm-minus (¼-in-minus) stone to completely fill the tunnel from the zone 3 backfill face to within 10.5 m (35 ft) of hole 2 (table 1).

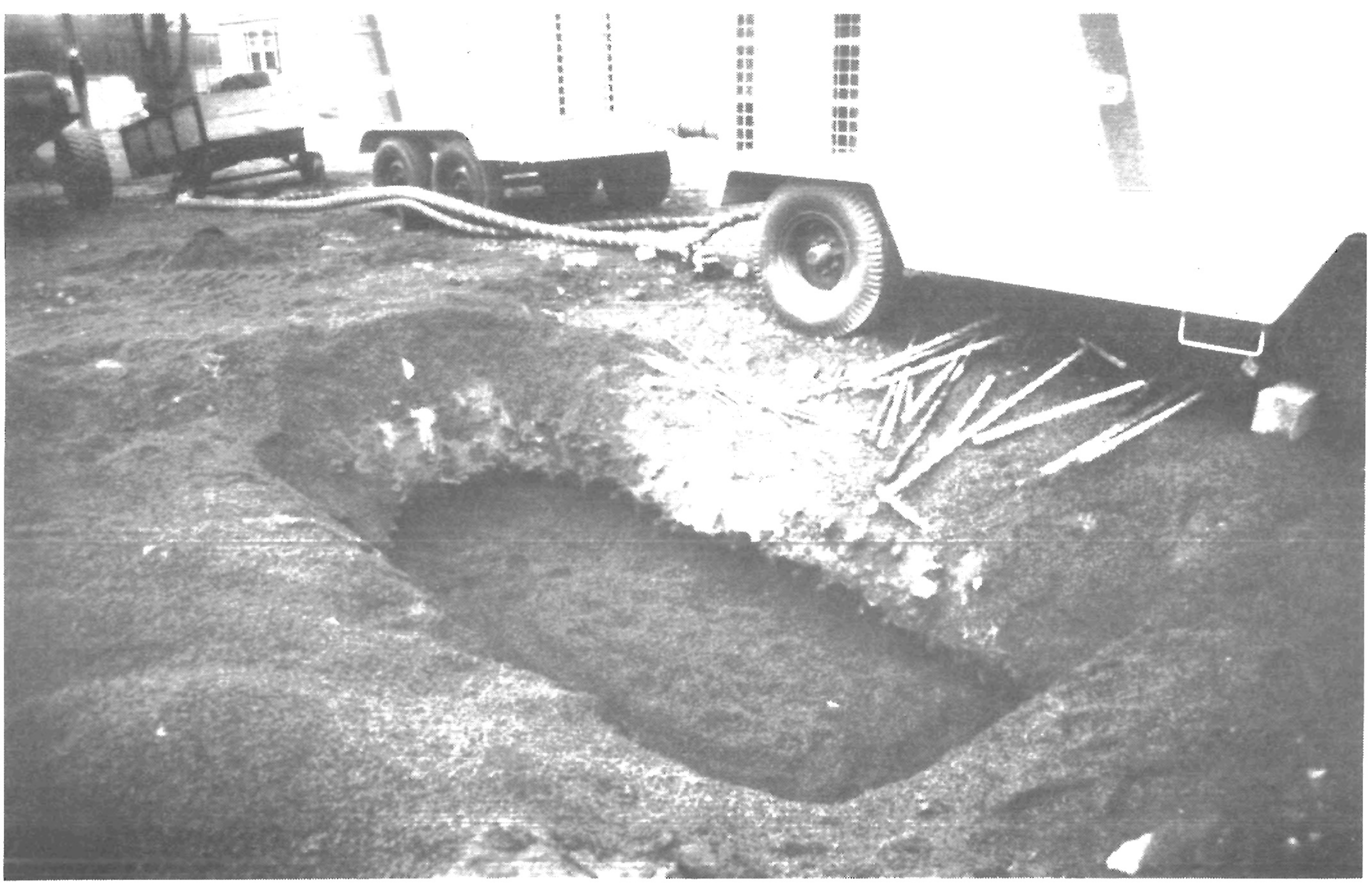
### High-Efficiency Ejector, Zone 5

The High-Efficiency Ejector was used to backfill the remaining 10.5 m (35 ft) of tunnel. The High-Efficiency Ejector was set up in hole 2 exactly as it had been in hole 1 for zone 3 backfilling. It took 1 working day and approximately 125 t (138 st) of 0.6-cm-minus (¼-in-minus) stone to completely fill zone 5 (table 2).

## SITE RESTORATION

Immediately upon completion of operations at hole 1, a steel rebar mat was constructed to the dimensions of the hole 1 opening, and 1.5 m$^3$ (2 yd$^3$) of concrete was poured. The concrete was poured directly onto the exposed backfill pile (figure 16), and it formed a plug within hole 1. The

*Figure 16*



*Hole 2 after completion of backfilling operations.*

top of the concrete plug was approximately 0.3 m (1 ft) higher than the top of the tunnel roof. Fill material was then placed and compacted over the plug, and the street was patched. Upon completion of hole 2 operations, a second concrete plug was constructed in the same fashion as the plug for hole 1.

## RESULTS

The project was completed with 1,177 t (1,297 st) of 2.5-cm-minus (1-in-minus) stone and 998 t (1,101 st) of 0.6-cm-minus (¼-in-minus) stone, for a total of 2,175 t (2,398 st) to completely fill the tunnel. This demonstration was accomplished in 23 working days, and backfilling amounted to an overall daily tonnage rate of approximately 111 t/d (122 st/d). However, since this was the first practical demonstration of the Pneumatic Pipefeeder and the High-Efficiency Ejector, much was learned about operational requirements of the two devices as the demonstration progressed. The average daily tonnage rate in the first 10 days was approximately 64 t/d (70 st/d), but the rate for the remaining 13 days was over 118 t/d (130 st/d). Tables 1 and 2 show the overall performance of the Pneumatic Pipefeeder and the High-Efficiency Ejector during the demonstration.

### PNEUMATIC PIPEFEEDER

#### Performance

The Pneumatic Pipefeeder was used for 21 working days to fill approximately 88% of the tunnel. During this time, the Pneumatic Pipefeeder backfilled approximately 1,177 t (1,297 st) of 2.5-cm-minus (1-in-minus) stone and 741 t (817 st) of 0.6-cm-minus (¼-in-minus) stone into the tunnel at an average rate of 63 t/d (69 st/d) for zone 1, 110 t/d (121 st/d) for zone 2, and 124 t/d (136 st/d) for zone 4 (table 1). The difference in tonnage rates among zones 1, 2, and 4 is attributed to increased efficiency and experience in operating the Pneumatic Pipefeeder.

The backfill placed by the Pneumatic Pipefeeder completely filled the tunnel opening, and the high velocity of the backfill exiting the pipeline created a tightly packed pile within the tunnel. The backfill pile placed in the tunnel was in fact so tightly compacted that it could support the weight of a person standing on the pile, without sloughing.

#### Difficulties and Solutions

The major difficulty encountered while the Pneumatic Pipefeeder was operated was that of wear on the pipeline caused by the abrasion of the high-velocity backfill in the pipe. The high-density polyethylene pipe used at the start of the demonstration quickly proved to be inadequate to withstand the relatively high abrasion forces exerted on it by the backfill material. Reducing the radius of curvature of the pipeline mitigated this problem somewhat, but the high-density polyethylene was simply not a suitable material for the pipeline. The wear problem was minimized by replacing the high-density polyethylene pipe with Schedule 10 steel pipe; and with the addition of several sections of Schedule 40 steel pipe, the pipeline was able to survive the life of the project. Even with the steel pipe sections, however, at any locations where the pipeline was allowed to bend sharply, localized premature wear of the pipeline could be noted. Thus, it is important to maintain gentle curves throughout the pipeline and to maintain the pipeline in the straightest configuration possible. This was accomplished in the demonstration by placing the Pneumatic Pipefeeder directly on the tunnel floor and gradually raising the pipeline up throughout its length with wood crib blocks so that the end of the pipeline was approximately 1.2 m (4 ft) off the floor and aimed at the top of the backfill pile.

Another problem associated with the Pneumatic Pipefeeder was that the pipeline became plugged with backfill. Although this nuisance did not result in significant delays during the project, it was completely avoidable. The plugging of the pipeline was caused when the air supply to the Pneumatic Pipefeeder was turned off while the Pneumatic Pipefeeder's conical hopper was still loaded with backfill. When the air supply was turned back on, the weight of the backfill remaining in the pipeline could not be moved with the air. Researchers discovered that by emptying the conical hopper and allowing the empty Pneumatic Pipefeeder to remain in operation for several minutes, the pipeline would completely clear of all backfill, thus allowing easy restarts of the system.

A potential problem inherent in both the Pneumatic Pipefeeder and the High-Efficiency Ejector is that of noise. It was quickly discovered that both devices generate significant levels of noise while in operation, so tests were conducted to determine overall noise levels proximal to the two devices and around the job site. A series of dosimeter measurements made at the Pneumatic Pipefeeder and High-Efficiency Ejector locations and moving away from each device at 3-m (10-ft) intervals indicated that noise levels were dependent upon the level of backfill allowed to remain in the intake hopper during operation. For instance, at tonnage rates that allowed the intake hopper to remain empty, the noise level at the hopper location was approximately 130 dB, and the noise level 15 m (50 ft) from the hopper dropped to 106 dB. When the tonnage rates were increased so that the intake hopper remained completely full of backfill, the noise level was reduced to 104 dB at the hopper, 82 dB 15 m (50 ft) from the hopper, and below 70 dB 30 m (100 ft) from the hopper. Figure 17 show the results of the noise level testing.

## HIGH-EFFICIENCY EJECTOR

### Performance

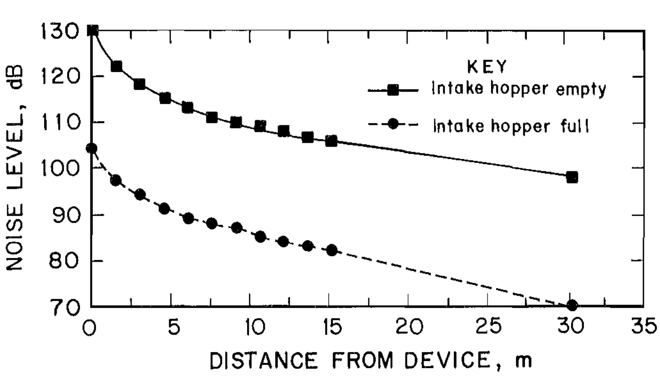
The High-Efficiency Ejector was used for 2 working days to fill approximately 12% of the tunnel. During this time, the High-Efficiency Ejector backfilled approximately 257 t (284 st) of 0.6-cm-minus (¼-in-minus) stone into the tunnel at an average rate of 132 t/d (146 st/d) for zone 3 and 125 t/d (138 st/d) for zone 5 (table 2). Like the backfill placed by the Pneumatic Pipefeeder, the backfill placed by the High-Efficiency Ejector completely filled the tunnel opening, and the high velocity of the backfill redirected by the nozzles created a tightly packed pile within the tunnel.

### Difficulties and Solutions

There were no operational difficulties encountered while using the High-Efficiency Ejector. The only practical problem encountered was how to attach it firmly to holes 1 and 2. This problem would not be encountered in a field situation, since the High-Efficiency Ejector is designed for use in a borehole. It was demonstrated, however, that the High-Efficiency Ejector is a useful tool for situations encountered on projects similar to this demonstration.

Researchers discovered while backfilling zones 3 and 5 that as the backfill pile approached the High-Efficiency Ejector, the high-velocity airstream generated by the nozzles would begin blowing backfill out of the access hole. This problem was solved by running only one air compressor as the backfill pile neared the High-Efficiency Ejector. When the backfill pile was very close to the device, the operating compressor was valved shut so that only a minimal supply of air was delivered to the High-Efficiency Ejector. In this way, the exit velocity of the air could be closely regulated, resulting in virtually no backfill being blown out of the tunnel.

*Figure 17*




***Typical noise levels at site during operation of Pneumatic Pipefeeder and High-Efficiency Ejector.***

## OVERALL PROJECT COST

Table 3 shows the costs of the backfilling demonstration that were shared by OSM and the USBM. The USBM and OSM provided technical oversight to the project; the labor and travel costs for this involvement are not reflected in the project cost total in table 3. Also not included are the labor and travel costs associated with the USBM's contractor who provided additional technical expertise and through whose project this demonstration was funded. The labor provided by the USBM was to monitor the demonstration and to make measurements and observations from a research standpoint only; this labor had little impact on the timing or duration of the demonstration. Daily measurements and other research-oriented activities, however, probably extended the overall project duration by 1 or 2 days.

**Table 3.—Overall project costs**

| Item | Quantity | Unit cost | Total cost |
|---|---|---|---|
| Operations: | | | |
| Mobilization | 1 | $3,051.00 | $3,051.00 |
| Demobilization | 1 | 3,051.00 | 3,051.00 |
| Excavate and backfill, $yd^3$ | 120 | 10.00 | 1,200.00 |
| Pave, $yd^2$ | 14 | 30.00 | 420.00 |
| Equipment: | | | |
| Air compressors, h | 232 | 32.76 | 7,600.00 |
| Hopper-conveyor, h | 232 | 23.00 | 5,336.00 |
| Fuel, gal | 3,625 | 0.80 | 2,900.00 |
| Labor: | | | |
| Loader-backhoe operator, h | 263 | 41.00 | 10,783.00 |
| Hopper-conveyor operator, h | 263 | 27.00 | 7,101.00 |
| Materials: | | | |
| Schedule 10 pipe, lf | 525 | 6.50 | 3,412.50 |
| Schedule 40 pipe, lf | 105 | 8.50 | 892.50 |
| Pipe couplings | 30 | 23.00 | 690.00 |
| Backfill, ¼-in-minus, st | 1,443 | 15.00 | 21,645.00 |
| Backfill 1-in-minus, st | 955 | 10.00 | 9,550.00 |
| Wood crib block (6X6), lf | 40 | 2.50 | 100.00 |
| Concrete, class C, $yd^3$ | 3 | 75.00 | 225.00 |
| Project total | | | $77,957.00 |

NOTE.—Costs were based on customary units, not metric, and reflect 1991 prices.

Also not included in the overall project costs shown in table 3 are the fabrication costs associated with the

Pneumatic Pipefeeder and the High-Efficiency Ejector. These two devices were designed under the USBM's Abandoned Mine Reclamation Research Program, and final reports have been written detailing their design, operation, and performance (*1*).[7] The actual costs associated with fabricating these two devices is minimal when compared with the overall costs associated with a backfilling project. The Pneumatic Pipefeeder and the High-Efficiency Ejector used for this demonstration were fabricated at a cost of $3,000 and $2,000, respectively. Further, repairing any worn areas on these two devices is simple and inexpensive. Past work has shown that steel plate welded over worn areas of the Pneumatic Pipefeeder is satisfactory for significantly extending the useful life of the device.

It was evident at the end of the demonstration that minimal labor requirements are necessary to conduct a remediation project using either the Pneumatic Pipefeeder or the High-Efficiency Ejector. The remediation crew for this demonstration consisted of a front-end loader operator, a conveyor belt operator, and a laborer. The front-end loader operator and the conveyor belt operator also served as laborers to install and maintain the Pneumatic Pipefeeder, High-Efficiency Ejector, and all support equipment and materials.

[7]Also covered in first contract report listed in footnote 5.

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