A MINING RESEARCH CONTRACT REPORT

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DESIGN AND EVALUATION OF A REMOTE AIR-JET PNEUMATIC STOWING SYSTEM

CONTRACT J0388015
L.C. HANSON COMPANY

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

FOREWORD

This report was prepared by L.C. Hanson Company, Helena, MT under USBM Contract number J0388015. The contract was initiated under the Abandoned Mine Land Research Program. It was administered under the technical direction of the Branch of Procurement-Pittsburgh with Jeffrey S. Walker acting as Technical Project Officer. Mrs. Gerry M. Puskar was the Contract Administrator for the Bureau of Mines. This report is a summary of the work completed as a part of this contract during the period from September, 1988 to March, 1990. This report was submitted by the authors on June 30, 1990.

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The section within this report discussing the operation of the Remote Air-Jet Pneumatic Stowing System is confidential and proprietary information (pp 19-29).

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

%	percent	in H_2O	inches of water
°F	degrees Farhrenheit	lin ft	lineal foot
cfm	cubic feet per minute	pcf	pounds per cubic foot
cu yd	cubic yard	psi	pounds per square inch
ft	foot	scfm	standard cubic feet per minute
hr	hour		
in	inch	tph	tons per hour

DRAFT FINAL REPORT

REMOTE AIR JET BACKFILL

Lowell C. Hanson[1]

*** ABSTRACT

During the early 1980's, remote pneumatic stowing was advocated as a means to fill dry mines. Remote stowing was emphasized because some available methods required admittance of workers to the mine workings to operate the conveyance system, and many of the mine workings were not considered sufficiently safe for such procedures. The goal of this report was to further investigate a unique system known as the Remote Air-Jet Pneumatic Stowing System. This investigation included records of past performance, improvements to existing equipment, full scale field testing to develop operational parameters for equipment and materials, and recommendations for any needed modifications to the system to optimize performance.

[1]Principal civil engineer

INTRODUCTION

The pneumatic stowing method works very well but is under utilized nationwide. Wider acceptance and greater implementation of the method could be achieved through documentation of the methodology and actual demonstrations.

Remote backfill of abandoned mine workings has been utilized for subsidence control and prevention in many instances. Several methods, such as hydraulic or pneumatic backfill, are available and applicable, depending on site conditions. For dry mine environment, the practice is to keep the mine dry during any stowing process. This practice limits backfill methods to pneumatic stowing or pressure grouting.

During the early 1980's, remote pneumatic stowing was advocated as a means to fill dry mines. Remote stowing involves the practice of placing a backfill material within subsurface voids via boreholes from the surface to the mine voids, utilizing compressed air to project the material within the mine void. Remote stowing was emphasized because some available methods required admittance of workers to the mine workings to operate the conveyance system, and many of the mine workings were not considered sufficiently safe for such procedures.

By using granular material, good support of the mine roof can be achieved. Past projects have shown that the method can achieve roof contact in many instances. In all cases, 90% of the room height is successfully filled. On past projects, cementitious grout has been pumped into the pneumatically filled voids to assure total fill of the void space and uniform support of the roof. *(1-5)*[2]

The remote backfill process requires television monitoring of the fill and exploration of the voids prior to filling. Boreholes, usually 8 in. in diameter are drilled from the ground surface to the mine void. The television survey equipment is lowered into the mine workings and the geometry of the void is determined and plotted on a map. Subsequent boreholes are located on the surface so that they will encounter the void when drilled. When sufficient information is learned about the mine, the remote backfill process can be planned. By working from the extremities of the mine and retreating to strategic locations, the voids are systematically filled.

The cost for remote backfill is dependent on the number and length of boreholes drilled, cost of backfill material, and efficiency of the operation. By maximizing the distance the equipment will project backfill material into the void, we can increase the distance between boreholes and reduce the cost for drilling. Past projects have been planned for boreholes spaced at 30 ft. maximum. *(1-5)*

The rate at which material can be stowed further influences the cost. Past projects were planned for a yield of 25 tph. Actual production

[2] Italic number in parentheses refers to items in the List of References.

amounted to far less because of limited operational skills and equipment deficiencies.*(1-5)*

Virtually any type of backfill material can be stowed. Rounded particles of uniform size produce the best results but even very fine sand can be successfully stowed. Normally pit run gravel screened to 3/4 in. or 1 in. minus is readily available. Data pertaining to variables in material type and rate of stowing is virtually lacking except for what we have developed on past projects. Proper tests and classification of materials have not been conducted. Greater cost effectiveness is achieved by utilizing local waste materials, provided the rate of stowing can be kept high.

Proper operation requires trained personnel with access to proven information about the factors which affect production and effectiveness of the system. Air flow volume, air pressure, material feed rate, material properties, moisture content, and particle size are all factors which affect the effectiveness and efficiency of the system. Operation parameters for the system are virtually unrecorded and not available to operators and project planners.

Optimization of the method requires proven information which addresses the following: required equipment and materials; necessary adjustments to these elements; and the resulting underground accomplishments. Important among these factors is stowing material variation, such as particle size, gradation, and moisture content. These are usually site specific and subject to less control than some other methods. The goal of this effort was to further investigate the remote backfill system, document past performance, improve equipment, and develop operational parameters for equipment and materials.

BACKGROUND

The Montana Abandoned Mine Reclamation Bureau (MAMRB) was planning reclamation at several project sites where subsidence was threatening surface structures. They contracted with L.C. Hanson Company to develop plans for subsidence control at several sites. The first project was the Lekvold-Shaw project near Scobey, Montana, which was undertaken in 1982.*(2)*

The MAMRB were asked for an evaluation of a remote stowing method which utilized high volume, low pressure air in a backfill conveyance process. Certain mechanical elements of the system were found to be short lived and unreliable with apparent high operational cost. This short coming initiated an investigation of a totally different concept which used high pressure air at fairly high volumes to place backfill material at the mine level. Gravity was to be the primary means of conveying the backfill material from the surface, via borehole, to the mine workings.

Laboratory experiments on the new method began during September and October of 1982. As a result of these efforts, the type of equipment which was necessary for the process and the apparent production rates were developed for the remote backfill of mine workings utilizing air and granular backfill materials. Realistic performance criteria and production rates were established which could be achieved in the field.

The Lekvold-Shaw project was completed under the competitive bid process and the low bidder utilized other stowing methods for performing the work. Engineers reviewed all work performed and made observations which substantiated the superior capabilities of the RAJPSS. From 1982 through 1986, stowing methods similar to the current RAJPSS were used at four sites within the state of Montana.*(1,3,4,5)* Over 18,000 tons of backfill material have been stowed into mine workings and over 90% of the targeted voids have been backfilled.

Past performance of the RAJPSS has demonstrated that the present equipment will stow certain backfill material through boreholes spaced at 30-ft. centers with an average production rate approaching 20 tph. Indications are that this equipment, when modified, can permit a significant increase in the borehole spacing, thus reducing the number of boreholes and equipment setups.

RAJPSS was developed as an economical and effective means for filling dry abandoned mine workings. The method is best suited to large open voids with few blockages. Smaller voids can also be filled but more boreholes need to be drilled into the mine workings and higher costs result. A schematic of the RAJPSS is presented in figure 1.

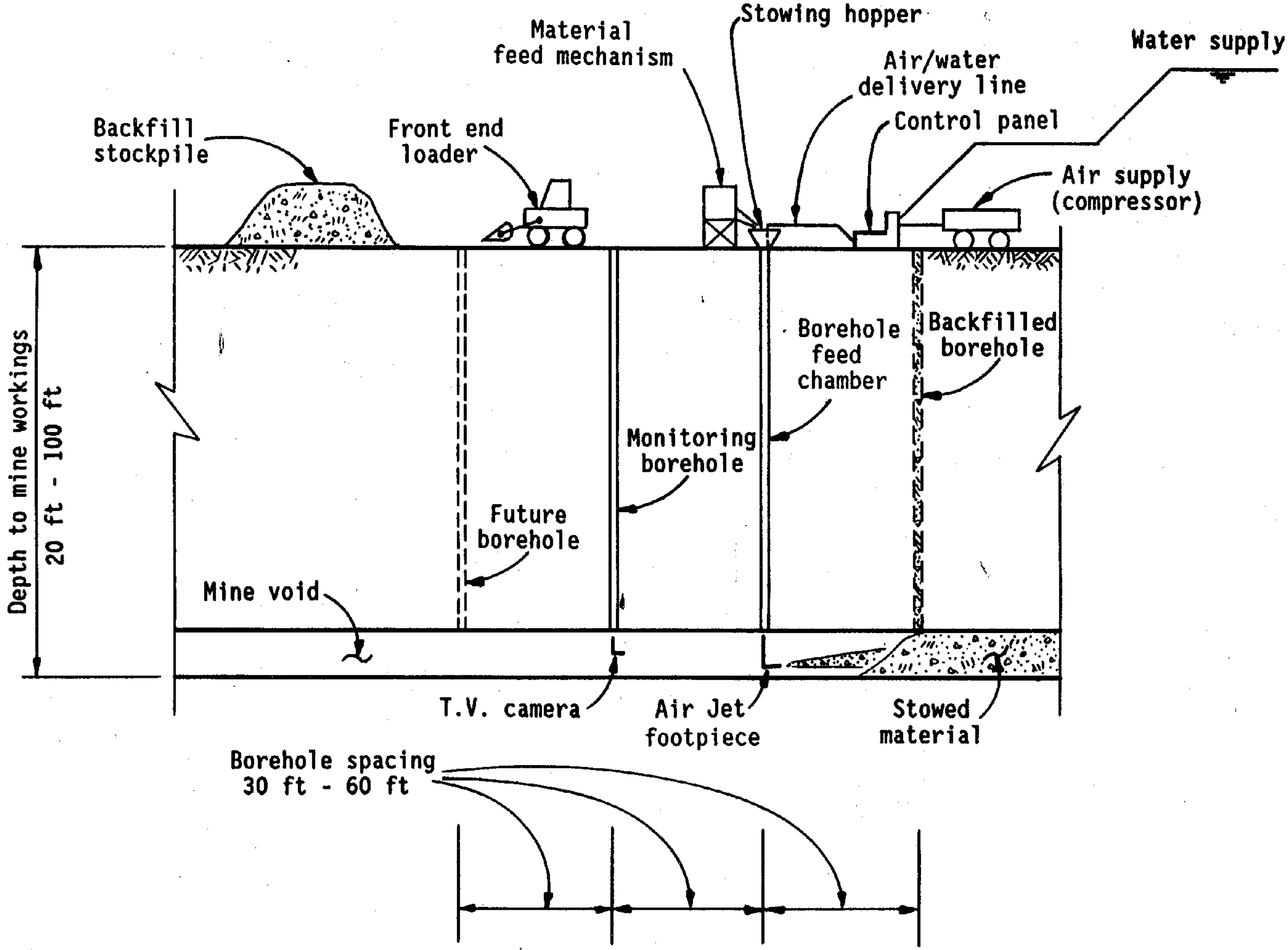


FIGURE 1. - Schematic of the RAJPSS for remote backfill of mine workings.

Past Performance

During the Spring of 1984, a full scale test of the RAJPSS was conducted at Helena, Montana. A 6 ft. wide by 6 ft. high by 40 ft. long simulated mine void was constructed. An early version of the air jet footpiece was set up and a 1200 cfm air supply was available to propel backfill material into the simulated mine void. The backfill material was 3/4 in. maximum size and was open graded. The test was of short duration and was completed in 2 hrs. The equipment stowed the material at over 30 tph and projected the backfill into the simulated mine void more than 30 ft. The test was very successful and demonstrated the equipment's capabilities for utilization in actual mine backfill projects.

The system has been utilized in the successful completion of four remote backfill subsidence control projects in Montana. The projects were called the Storm King, Knobloch, Coalridge, and Hancock Mines.

Much useful information was gathered and recorded in project files during these completed backfill projects. These projects provided the opportunity to observe system performance and recognize needed improvements which would improve system performance and reduce overall costs. Since the work at each of the sites was performed by independent construction contractors, the remote backfill system used could only be observed and verified that the backfill met the requirements of the contract.

The Storm King project was completed during 1984.*(3)* The project is located in Miles City, MT and involved mine workings underlying U.S. Highway 12. The mine workings were 25 ft below the level of the highway and the rooms were about 20 ft in width and 12 ft in height. Boreholes were drilled from the surface to the mine workings at a spacing of 30 ft maximum. A total of 1211 lin ft of 10 in diameter borehole (for remote stowing) and 652 lin ft of 6 in borehole (for exploration) were drilled from the surface to the mine workings.

A total of 9541 tons of backfill material were stowed into the mine voids via the network of boreholes, utilizing the remote air-jet system. The ratio of tons stowed to lin ft. of borehole was 7.9. The backfill material was comprised of fine sand which was a waste material from the local gravel producing operation in nearby Miles City, MT. The performance specifications for the project called for the mine voids to be completely filled from floor to within 10% of the total room height. This was achieved and verified by a remote subterranean television survey system.

The total cost for the above-described quantities, including mobilization of crews and equipment, was $180,521, as shown in table 1. This amounted to $18.92/ton of material stowed into the mine workings.

Another remote backfill project completed by the air jet method was the Knobloch project located near Birney, MT.*(1)* Mine workings extended

TABLE 1. - Summary of costs for past pneumatic stowing projects.

Project name	Construction costs ($)					Comparisons			
	Mobilize	Drilling	Provide material	Stow material	Total cost	Tons stowed	Drill footage	*Cost Per ton ($)	Tons stowed per lin. ft. of borehole
Storm King	$70,050	$11,505	$40,290	$58,676	$180,521	9541	1211	$18.92	7.9
Knobloch	5,500	4,380	---	4,440	14,320	5956	2440	23.34	2.4
Coalridge	34,100	33,480	31,220	40,200	139,000	1967	5833	26.34	0.4
Hancock	5,000	17,499	19,674	9,640	51,813	500	292	28.64	1.7

* Cost of exploratory drilling not included.

under a driveway to a rural residence and potentially impacted the residence itself. A remote backfill contract was performed during 1986.

A total of 292 lin ft. of 10 in. boreholes were drilled into the mine void at a maximum spacing of 30 ft. A total of 370 cu yds of backfill material were stowed into the mine workings, which is approximately equal to 500 tons. The ratio of tons stowed per lin ft. of borehole was 1.7. Total cost of backfill operation including mobilization was $14,320 or $28.64/ton. This relatively high cost is attributable to the remote location of the site and a very small contract amount. A summary of costs is shown in table 1.

During 1985, a section of Sheridan County Highway No. 516 was found to be partially undermined by an abandoned coal mine.*(4)* The remote air jet backfill system was used to backfill mine voids and partially stabilize the ground surface and prevent further subsidence. Nearly one-half mile of highway was affected. Since no mine maps existed, the need for remote subterranean survey was evident. The project was called Coalridge, named after the small coal mining town at the site.

During the course of the project, 2440 lin ft of 8 in. diameter boreholes were required. A total of 5956 tons of backfill materials were stowed. The ratio of tons stowed per lin ft. of borehole was 2.4. The material consisted of two types - one material was 3/4 in. minus gravel with 27% passing the No. 4 sieve, and the second type was 1/2 in. minus with 17% passing the No. 4 sieve. The second material generally stowed more easily than the first type. The total cost for stowing material by the air jet method was $139,000 as shown in table 1.

The average cost per ton was $23.34/ton. Backfill materials were hauled more than twenty miles. Much of the work was performed during winter and periods of very adverse weather.

The most recent remote air jet backfill project was located near Reserve, MT at the abandoned Hancock Mine.*(5)* The mine was found to underlie a county road. A total of 5833 lin ft of 8 in. diameter boreholes were drilled from the ground surface to the mine void and utilized for stowing backfill materials. Backfill material was screened pit run gravel and 1967 tons were stowed into the mine voids. The tons stowed per lin ft. of borehole was 0.4. The total cost for performing the remote stowing was $51,813, as shown in table 1. The unit cost for stowing backfill materials was $26.34/ton. The backfill materials were hauled to the site from a source located more than 20 miles distant. Because of the mine geometry, a higher than normal number of boreholes were necessary to complete the backfill operation. These factors and the remote location were primary elements contributing to the higher than normal cost.

SYSTEM OPERATION AND DESIGN IMPROVEMENTS

The RAJPSS depicted in figure 1 consists of a material feed mechanism, stowing hopper, borehole feed chamber, air and water delivery line, control panel, and air-jet footpiece. The system operates on compressed air and gravity to convey the fill material from ground level to the mine level.

The system operation initiates with select backfill material loaded into the feed mechanism. This mechanism can be a belt conveyor or hopper. The function of the feed mechanism is to regulate material feed rate and provide for uniform feed. The capacity of the stowing system will be increased if the material is fed at a uniform rate. Surge feeding tends to overload and plug the system. A regulated flow of stowing material is uniformly released from the feed mechanism directly into the stowing hopper.

The stowing hopper is located directly over the borehole. The primary function of the stowing hopper is to direct the backfill material into the feed chamber. This hopper acts as a funnel or intake device to transition the material into the borehole feed chamber and direct backfill downward by gravity conveyance. This hopper can also be utilized for regulating or measuring material feed rate.

The borehole feed chamber may be a cased borehole, open borehole, or a combination of each extending into the mine void. Overburden characteristics generally dictate the type of feed chamber required. The opening of the chamber or borehole must be a minimum of 8 in. diameter for current system operation. This diameter allows for adequate material feed rate and lowering of the necessary system elements into the targeted mine void.

A properly sized delivery pipe is placed within the feed chamber/borehole and utilized for delivering compressed air or water to the footpiece. This pipe is located on the inside of the chamber and placed to one side so as not to obstruct material feed. The air and water delivery pipe extends from the control panel at the surface to the air-jet footpiece located within the mine. Water injection capabilities were incorporated to test the effects of moisture on the material stowing rate. Normal stowing projects would generally not utilize this capability.

The footpiece depicted in figures 2 and 3 is considered the primary element of the RAJPSS. This remote device can be lowered into an 8 in. diameter borehole and secured at the desired mine level. The footpiece connects to the air and water delivery pipe prior to placement within the mine void. The footpiece generally consists of an air/water delivery pipe, secondary material feed chamber, air/material mixing chamber, interchangeable air nozzles, deflector plate, and trajectory barrel with tilt arm. The overall footpiece is approximately 6 ft. long when extended in a position for lowering into the mine void. As stowing material falls down the borehole feed chamber, it passes into the air jet footpiece and undergoes a series of directional and velocity changes. As the material is propelled laterally by the compressed air, it passes through the footpiece barrel which can manipulate the trajectory of the airborne particles prior to exiting the footpiece. The barrel is put to the desired horizontal position once the footpiece is placed within the mine. The air nozzle within the footpiece is interchangeable, allowing varying

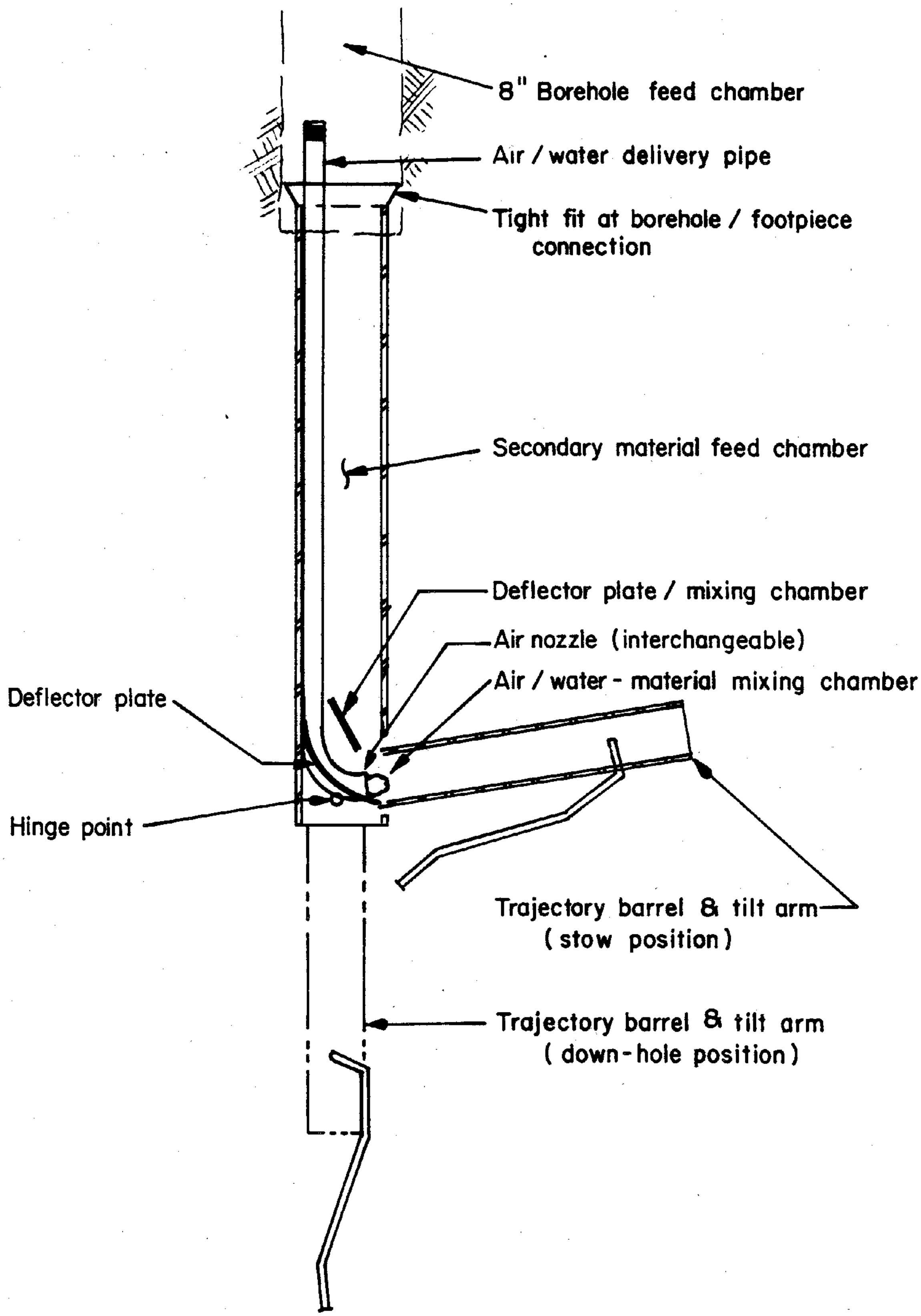
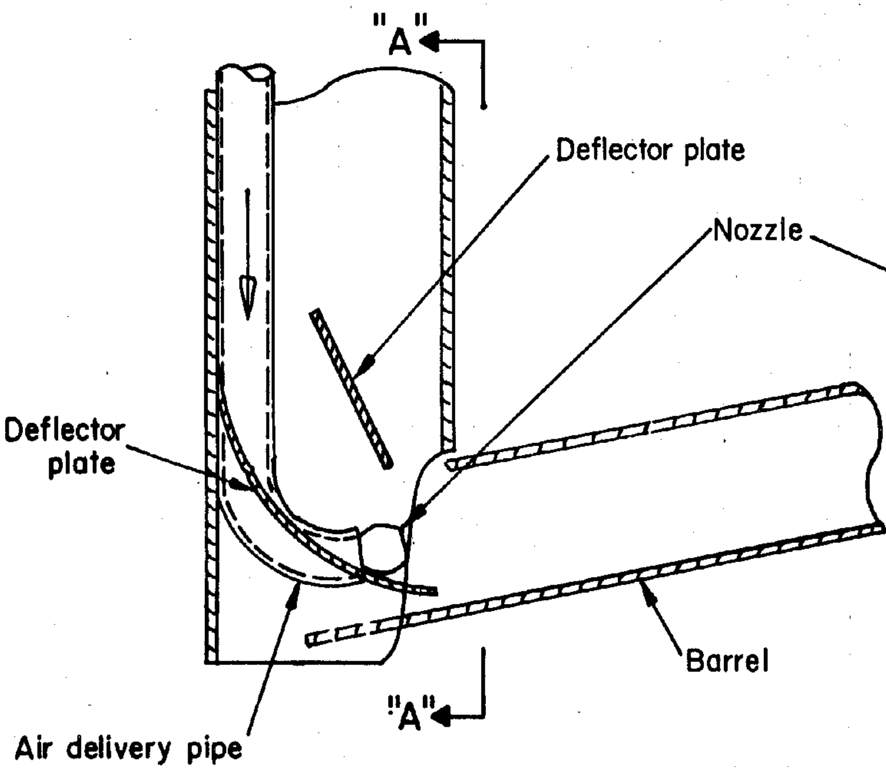
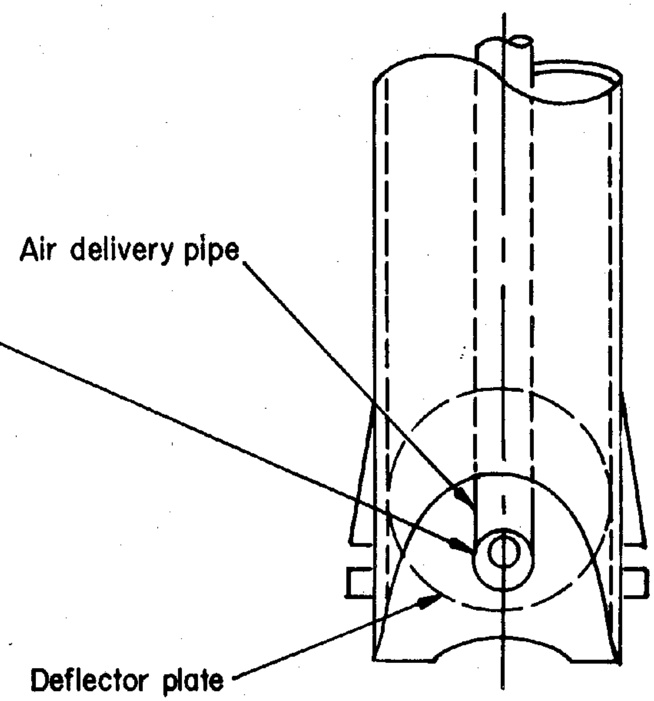


FIGURE 2. - Elevation view of footpiece.



Enlarged view of nozzle area



Section "A-A"

FIGURE 3. - Enlarged view of nozzle area and detail section A-A.

sizes to be threaded onto the air delivery line, altering air pressure to match material characteristics. A key aspect of the air jet is its ability to change the flow of air and material from vertical to horizontal while maintaining laminar flow which can effectively fill the mine voids.

Strict control over the system is obtained with the control panel. The operator must monitor the stowing process from one location. This panel consists of a group of gauges and valves which will measure air pressure and air flow and a control valve to vary quantity of air supplied. It also contains a water pressure gauge and flow meter along with a control valve for regulating water flow. The panel is designed to be placed adjacent to the stowing borehole along with a control for adjusting material feed rate. Air and water are delivered to the control panel within separate delivery lines. Only one delivery pipe exits the panel however, and extends down the borehole feed chamber.

Monitoring of equipment performance and development of operational parameters can be accomplished with the control panel. The performance of the system is monitored while recording material feed rate, air flow, water flow, air pressure, and water pressure. The system operation can be optimized from the data recorded from this control panel. During actual stowing operations, the control panel allows the operator to make the necessary adjustments to accomplish the backfill in the most efficient and effective manner possible. Figures 4 and 5 show separate views of the control panel developed for the tests.

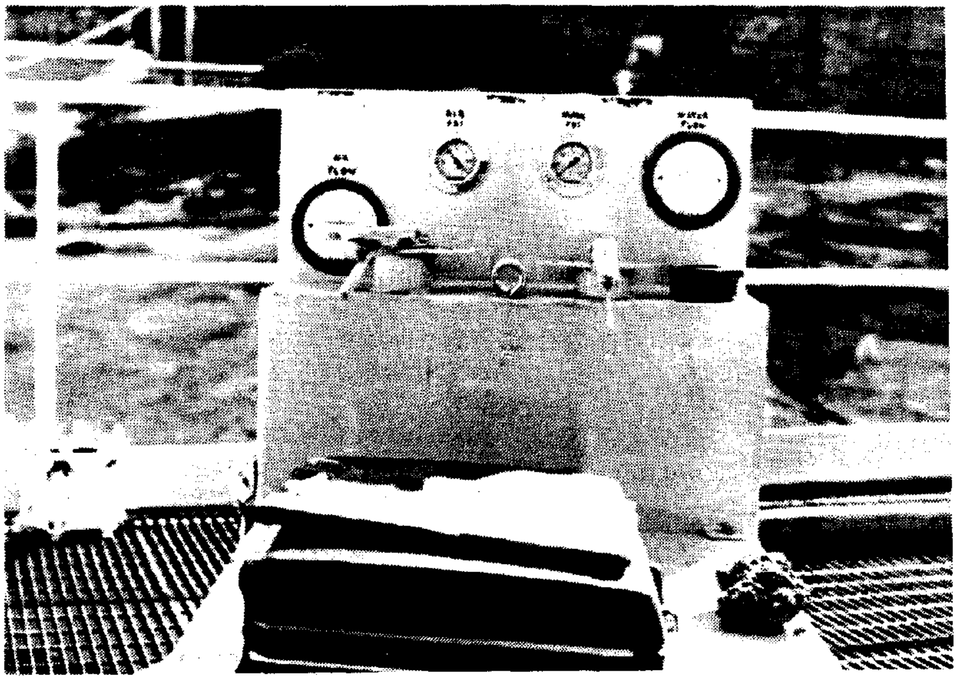


FIGURE 4. - View of control panel console showing air and water gauges along with control valves.

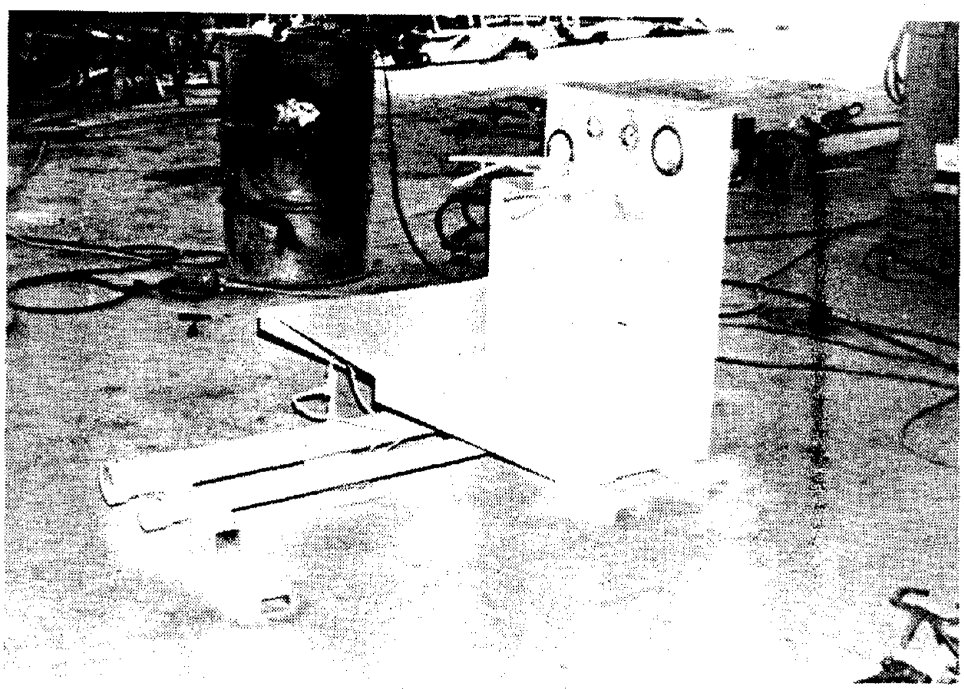


FIGURE 5. - Side view of control panel showing air delivery and smaller water delivery lines.

A principal objective of this contract was to develop a footpiece which incorporated improvements derived from observations at the Knobloch Mine, Storm King, Coalridge Emergency, and the Hancock Mine Stowing Projects. A second objective was to fabricate a control panel which would allow for measurement of air supply pressure and volume. Both of these objectives were met and the equipment was delivered to the Bureau of Mines test laboratory near Fairchance, Pennsylvania.

The improvements to the footpiece increased the distance which stowing material could be projected laterally. By increasing the effective stowing distance, drilling costs can be drastically reduced, resulting in a more favorable rate of tons stowed per lin ft. of borehole. Modifications were made which allowed the mix of air and stowing material to be confined in the footpiece mixing chamber, thereby controlling the performance of the stowing equipment. Additional modifications were the setting of the trajectory angle, optimization of air pressure, reduction of turbulence and resistance, and alignment of the air jet with the trajectory of the stowing material. Photographs of the air-jet footpiece are shown in figures 6 and 7.

The size of borehole required by the RAJPSS is determined by various factors such as overburden, soil conditions, need for casing pipe, depth to workings, and the size of tools to be utilized in the backfill operation. Presently, the RAJPSS utilizes an 8 in. diameter hole. This size adequately accommodates the stowing apparatus, air supply, and stowing material feed. This is considered to be the minimum size borehole

FIGURE 6. - Air jet footpiece lying on ground in extended position utilized when placing element into borehole. Footpiece barrel on right.

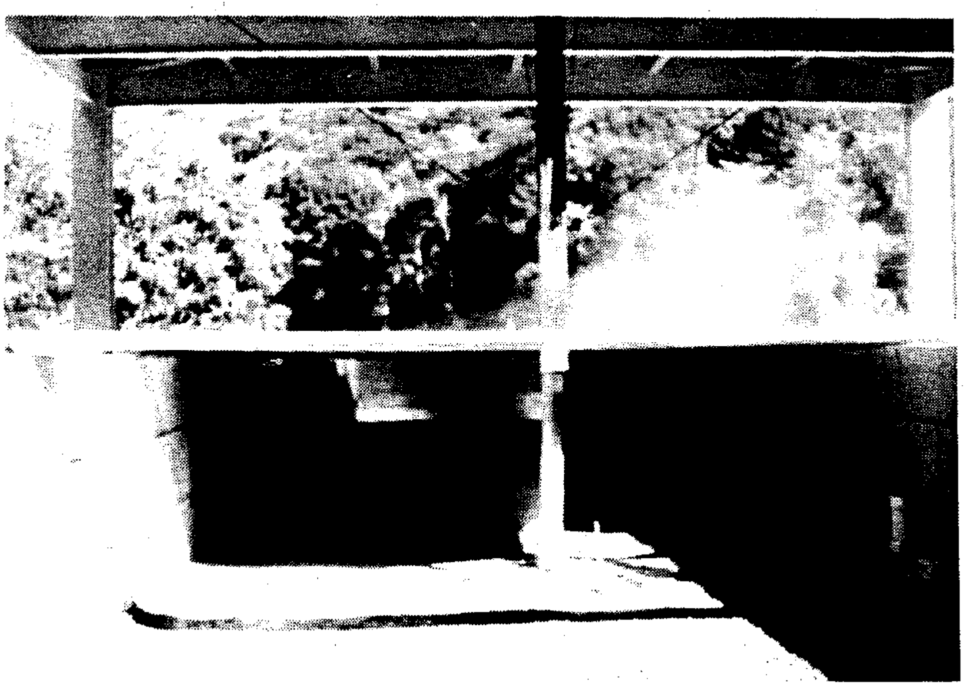


FIGURE 7. - View of system in operation at SAIL test site. Material being blown down the 100 lin ft. simulated mine void. Height of void is 6 ft.

suitable for the RAJPSS.

Setup of the RAJPSS within the remote mine void involves lowering the air supply pipe and the footpiece from the ground surface to the mine workings through the borehole. The air-jet trajectory is then remotely adjusted by a mechanical device which must be fabricated to suit the actual condition of the mine void.

Various tools have been utilized to manipulate the trajectory of the stowing material. The tests performed during this contract were made with an extension barrel placed on the footpiece to control the direction of stowing material. The barrel was effective in confining the trajectory and allowing the operator to place the stowing material directionally. Test time was not sufficient to allow for testing with the barrel removed. The barrel does wear due to abrasion and does restrict the quantity of material stowed per hour but the advantage of directional control is necessary in certain situations.

Nozzles are utilized to control the air stream. The RAJPSS will accept numerous nozzle types and sizes which may be utilized to fulfill a specific objective in the stowing operation. Air pressure and spray patterns are two variables which are considered in selecting a suitable nozzle. More investigation of the system component would provide data for consideration in selection of the most suitable nozzle type and configuration given backfill material and mine void configuration.

Many factors affect the performance of the RAJPSS. It was not the intent of this contract to consider any of the factors other than stowing material, air pressure, and air flow. The goal was to improve the equipment performance, operational parameters, and to disseminate information about the system capabilities and limitations to the industry.

The unit weight, moisture content, and particle size of the backfill material greatly affect the rate of backfill. Further testing will establish the extent each parameter affects the backfill rate. Properties of the air stream limit the rate of backfill extensively. The tests indicate that 100 psi air pressure and 1000 cfm air are required for a 30 ton/hour backfill rate.

SAIL TEST RESULTS AND ANALYSIS

The RAJPSS was tested at the U.S. Bureau of Mines Subsidence Abatement Investigation Laboratory (SAIL) facility located near Fairchance, PA. U.S. Bureau of Mines and L.C. Hanson Company representatives were on-site to conduct and observe the testing operations.

The primary purpose of the test was to examine the performance of the system within a simulated remote mine void environment. The initial test procedures were designed to demonstrate system capabilities and to develop performance data by varying backfill material feed rate, gradation, maximum aggregate size, moisture content, and air flow rate.

The overall performance of the newly-developed system was based on the rate at which the equipment could stow the material, the effectiveness of backfill placement, and the maximum distance the material could be effectively projected into the mine void.

The stowing system was located on a platform above a simulated mine void structure. Select backfill material was conveyed to the stowing hopper located above a borehole simulated with an 8-in. diameter casing. The borehole extended 30 vertical ft to one end of the simulated mine void. The stowing footpiece was positioned within the lower 2 ft of the mine void. The mine void dimensions were 6 ft high, 20 ft wide, and 100 ft in length. Air flow was supplied by two compressors having rated capacities of 1300 cfm and 1200 cfm, respectively. The system was intended to have a combined capacity of up to 2000 cfm of air flow at the borehole. However, even with both compressors operating at full capacity, gauge measurements indicated air flows which rarely exceeded 950 cfm at the borehole. The maximum capability of this stowing system was limited due to the reduced air flow.

Two different material gradations, labeled as sample No. 8 and sample No. 57 material, were utilized as backfill material. Sample No. 8 material was specified to have a maximum size of 1 in. and a uniform gradation of 1/4 to 1/2 in. diameter aggregate. Sample No. 57 material was specified to have a maximum size of 1-1/2 in. and a uniform gradation of 1/2 to 3/4 in. diameter. The results of actual sieve analysis and relative density determinations for each sample are shown in table 2.

TABLE 2. - Gradation and density values for stowing material.

SIEVE ANALYSIS
(Sample No. 8 stone)

Sieve	Percent passing	Specification requirements percent passing
1 in.	100.0	100
3/8 in.	94.3	85 - 100
No. 4	82.8	10 - 30
No. 8	22.9	0 - 10
No. 16	7.7	0 - 5

RELATIVE DENSITY
(Sample No. 8 stone)

Maximum index density (pcf)	Minimum index density (pcf)
104.0	90.7

SIEVE ANALYSIS
(Sample No. 57 stone)

Sieve	Percent passing	Specification requirements percent passing
1-1/2 in.	100.0	100
1 in.	97.7	95 - 100
1/2 in.	21.0	25 - 60
No. 4	3.3	0 - 10
No. 8	2.1	0 - 5

RELATIVE DENSITY
(Sample No. 57 stone)

Maximum index density (pcf)	Minimum index density (pcf)
94.8	85.8

This stockpiled material was relatively wet as excessive moisture was visible on the surface of the aggregate. Because of the consistently moist condition of the backfill material, moisture variation was not introduced into the final test procedures. All tests were therefore performed at a very high moisture content.

Testing logs were recorded for each of three test sessions and are shown on tables 3 through 8. Each log presents data on the air flow and accompanying air pressure utilized during each test, times of operation, and notes on system operation. Material feed rate and moisture content of the backfill material could not be accurately determined. A synopsis of the test results and recorded observations is presented as follows:

Test No. 1

The results of this initial test basically demonstrated the system's capability to stow materials. Test data is shown in tables 3 and 4. No performance or efficiency data was obtained. Several tons of material were projected into the mine void with the majority of the material stowed 20 to 60 ft. from the borehole. However, material was projected over 100 ft., which was beyond the test facility mine void opening. Frequent plugging of the system footpiece during this initial test was a problem due to oversized rock (+ 3 in. diameter) entering the system. Material sample No. 57 had an excessive amount of the larger rock size, therefore, the majority of test No. 1, as well as the remaining tests, utilized material sample No. 8 which had the smallest aggregate sizes and was

TABLE 3. - Testing log for stowing test No. 1.

Test No.: 1 Location: SAIL Elev. 2001 MSL

Purpose of test: Initial operation. Nozzle size: 14/16 in.

Material type and description: No. 57 - 1½ in. minus, tan rock with no fines. (wet)

Time	Compressor 1			Compressor 2			Panel air			Panel H2O			Feed rate, tph	Air flow, scfm
	cfm	psi	°F	cfm	psi	°F	in.H2O	psi	°F	in.H2O	psi	°F		
9:00	1300	N.A.	N.A.	off	-	-	4.3	95	108	-	-	-	N.A.	681
9:05	1300	N.A.	N.A.	off	-	-	4.2	95	108	-	-	-	N.A.	673
	-System plugs, No. 57 material does not feed well. -Change to No. 8 material.													
9:10	1300	N.A.	N.A.	off	-	-	4.5	95	108	-	-	-	N.A.	697
	-System plugs, using too high of feed rate for given air flow. -System clears out plug itself once feed reduced.													
9:20	-Shut system down. Need to add shrouds to conveyor. -Start test over. Use No. 8 material with both compressors running.													
10:44	1300	N.A.	N.A.	1200	N.A.	N.A.	5.5	120	108	-	-	-	N.A.	854
	-System plugs at nozzle. 3 rocks found at approx. 3 in. dia. in size. must manually remove rocks this size. Continue test. Material projected blows ribbon off void roof at 50 feet.													
11:40	1300	N.A.	N.A.	1200	N.A.	N.A.	5.8	122	108	-	-	-	N.A.	883
11:50	1300	N.A.	N.A.	1200	N.A.	N.A.	5.8	123	108	-	-	-	N.A.	887

TABLE 4. - Continued testing log for stowing test No. 1.

Test No.: 1 **Location:** SAIL Elev. 2011 MSL

Purpose of test: Initial operation. **Nozzle size:** 15/16 in.

Material type and description: No. 8 - ½ in. minus gravel, angular, very wet.

Time	Compressor 1			Compressor 2			Panel air			Panel H2O			Feed rate, tph	Air flow, scfm
	cfm	psi	°F	cfm	psi	°F	in.H2O	psi	°F	in.H2O	psi	°F		
1:30	1300	N.A.	N.A.	1200	N.A.	N.A.	5.7	123	108	-	-	-	N.A.	879
2:00	-Numerous plugging problems are occuring due to oversize rock. -Remove existing nozzle and run with 15/16 in. size nozzle.													
2:40	1300	N.A.	N.A.	off	-	-	5.7	123	108	-	-	-	N.A.	879
	-Started second compressor.													
2:45	1300	N.A.	N.A.	1200	N.A.	N.A.	6.6	105	108	-	-	-	N.A.	882
2:50	-System plugs at nozzle. 3 rocks found at approx. 3" dia. in size.													
3:30	-End test no. 1													

N.A. - Not available

TABLE 5. - Testing log for stowing test No. 2.

Test No.: 2 Location: SAIL Elev. 2011 MSL

Purpose of test: Demonstrate ability of system to stow. Nozzle size: 15/16 in.

Material type and description: No. 8 - ½ in. minus gravel, angular, very wet.

Time	Compressor 1			Compressor 2			Panel air			Panel H2O			Feed rate, tph	Air flow, scfm
	cfm	psi	°F	cfm	psi	°F	in.H2O	psi	°F	in.H2O	psi	°F		
9:00	1300	N.A.	N.A.	1200	N.A.	N.A.	7.0	110	58	-	-	-	N.A.	970
	-Test starts with both compressors.													
9:17	1300	N.A.	135	1200	N.A.	N.A.	6.8	105	85	-	-	-	N.A.	914
9:25	off	-	-	1200	120.	140.	6.8	105	92	-	-	-	N.A.	
	-Compressor 1 shut down on its own. Not sure why?													
9:30	1300	N.A.	-	1200	-	-	7.4	113	92	-	-	-	N.A.	978
9:31	1300	122	170	1200	130	142	7.5	113	94	-	-	-	N.A.	983
9:32	1300	112	-	1200	115	-	7.4	113	93	-	-	-	N.A.	977
9:35	1300	-	-	1200	-	-	7.4	113	95	-	-	-	N.A.	976
9:40	-Hopper filled up at borehole, must have plug due to oversize rock in footpiece. -Found 1 - 3 in. or larger rock partially blocking outlet of footpiece.													
9:52	1300	-	-	1200	-	-	7.0	109	77.4	-	-	-	N.A.	922

TABLE 6. - Continued testing log for stowing test No. 2.

Test No.: 2 **Location:** SAIL Elev. 2001 MSL

Purpose of test: Demonstrate ability of system to stow. **Nozzle size:** 15/16 in.

Material type and description: No. 8 - ½ in. minus gravel, angular, very wet.

Time	Compressor 1			Compressor 2			Panel air			Panel H2O			Feed rate, tph	Air flow, scfm
	cfm	psi	°F	cfm	psi	°F	in.H2O	psi	°F	in.H2O	psi	°F		
9:55	-System beginning to plug again. Must have larger rock screened in future. -Found rock stuck in footpiece.													
10:06	off	-	-	1200	-	-	6.9	103	92.4	-	-	-	N.A.	907
	-Compressor 1 shuts down. Not sure why?													
10:33	off	-	-	1200	130	145	7.1	110	106.6	-	-	-	N.A.	935
	-This setup puts out more air with compressor 2 alone than with both compressors combined.													
10:40	off	-	-	1200	-	-	7.0	110	101	-	-	-	N.A.	933
	-Run out of diesel. Equipment shut down for repairs. -End of testing this day. -End of test no. 2													

N.A. - Not available

TABLE 7. - Testing log for stowing test No. 3.

Test No.: 3 Location: SAIL Elev. 2011 MSL

Purpose of test: Demonstrate and determine performance data. Nozzle size: 15/16 in.

Material type and description: No. 8 - ½ in. minus gravel, angular, very wet.

Time	Compressor 1			Compressor 2			Panel air			Panel H2O			Feed rate, tph	Air flow, scfm
	cfm	psi	°F	cfm	psi	°F	in.H2O	psi	°F	in.H2O	psi	°F		
8:40	off	-	-	1200	125	145	6.3	105	74.0	-	-	-	N.A.	889
-Preparing for material feed rate test only.														
9:30	off	-	-	1200	125	145	7.0	105	84.4	-	-	-	N.A.	928
9:31:00 -Begin stowing full borehole (0.46 cu.yd.).														
9:32:15 -Borehole clear. Total time = 75 seconds to clear 0.46 cu.yd.														
9:34	off	-	-	1200	125	145	7.0	105	82	-	-	-	N.A.	930
9:34:45 -Begin stowing full borehole (0.46 cu.yd.).														
9:35:50 -Borehole clear. Total time = 65 seconds to clear 0.46 cu.yd.														
9:36 -Begining stowing material continuously.														
10:03	off	-	-	1200	125	145	7.5	110	112.3	-	-	-	N.A.	956
10:25	off	-	-	1200	125	145	7.0	105	92.0	-	-	-	N.A.	921
10:40	off	-	-	1200	125	145	7.5	108	111.6	-	-	-	N.A.	949

TABLE 8. - Continued testing log for stowing test No. 3.

Test No.: 3 Location: SAIL Elev. 2011 MSL

Purpose of test: Demonstrate and determine performance data. Nozzle size: 15/16 in.

Material type and description: No. 8 - ½ in. minus gravel, angular, very wet.

Time	Compressor 1			Compressor 2			Panel air			Panel H2O			Feed rate, tph	Air flow, scfm
	cfm	psi	°F	cfm	psi	°F	in.H2O	psi	°F	in.H2O	psi	°F		
10:50	-Stop test to repair hole in barrel.													
1:15	-Ready to run again.													
1:30	off	-	-	1200	125	148	6.5	105	95	-	-	-	N.A.	885
1:45	off	-	-	1200	125	148	6.8	105	102.2	-	-	-	N.A.	900
1:48	off	-	-	1200	125	148	6.9	106	104.4	-	-	-	N.A.	905
	-Repairs to barrel cut capacity in half. Need reconstruction.													
2:20	off	-	-	1200	-	-	6.7	105	87.0	-	-	-	N.A.	905

-End stowing demonstration.
-Additional feed rate tests now indicate 14 cu.yd./hr. with barrel repair on footpiece.

N.A. - Not available

stowed with less difficulty.

Test No. 2

This test also resulted in a general demonstration of the system's capability to stow materials. The testing log is presented in tables 5 and 6. Again, no significant performance data could be accurately determined. General observations were made as to the way in which material was placed within the void. The material accumulated in the center of the void, creating a 1-1/2 ft. high pile 20 to 25 ft. from the footpiece. The stowed material then tapered down to a 1-ft. pile at 40 to 60 ft. Dunes which were created by the air flow were visible from 40 to 80 ft. With the footpiece tilted upward, material was hitting the roof from 13 to 30 ft. horizontally from the footpiece. Results of this test suggest that continued stowing would seal off the void at 20 to 25 ft. from the footpiece unless adjustments to the direction of the nozzle were made.

The material stowed during test No. 1 and test No. 2 was measured in place at the conclusion of the test day. Cross-sections and profiles of the stowed material are presented in figures 8 through 12. A total of 44.74 cu yds of material had been stowed at the end of test No. 2. A summary of the backfill measurements is presented in table 9.

Test No. 3

This final test also demonstrated the system's stowing capabilities while also measuring material stow rates. The stow rate was determined by filling the 8 in. diameter borehole casing throughout the 30 ft. length and recording the time it took to clear the system. The volume of the borehole casing and footpiece was calculated to be 0.46 cu yds. In two consecutive tests, the material was cleared in an average of 1.17 minutes. Therefore, a representative rate of stowing was established at 0.46 cu yds per 1.17 minutes which equates to just under 24 cu yds per hour. Based on a minimum material density of 91 pcf, the stowing rate is 29.5 tph at an air flow of 924 cfm with a pressure of 105 psi. A total of 12.6 cu yds of material were placed during test No. 3. Cross-sections and profiles of this fill are illustrated in figures 8 through 12. Completed test data is presented in tables 7 and 8.

The moisture content of the material was tested with a Speedy Moisture apparatus. Readings of 2.8% by weight were recorded, however, this value appeared low. This was the only moisture data available during the testing period. A sample of the material was transported to our laboratory and our tests confirmed the Speedy Moisture values.

SAIL DEMONSTRATION

CROSS SECTIONS OF TEST AREA

KEY

— — Cross section of material measured following test No. 2.
——— Cross section of material measured following test No. 3.
0+00 **Stationing in feet ahead of injection point.**

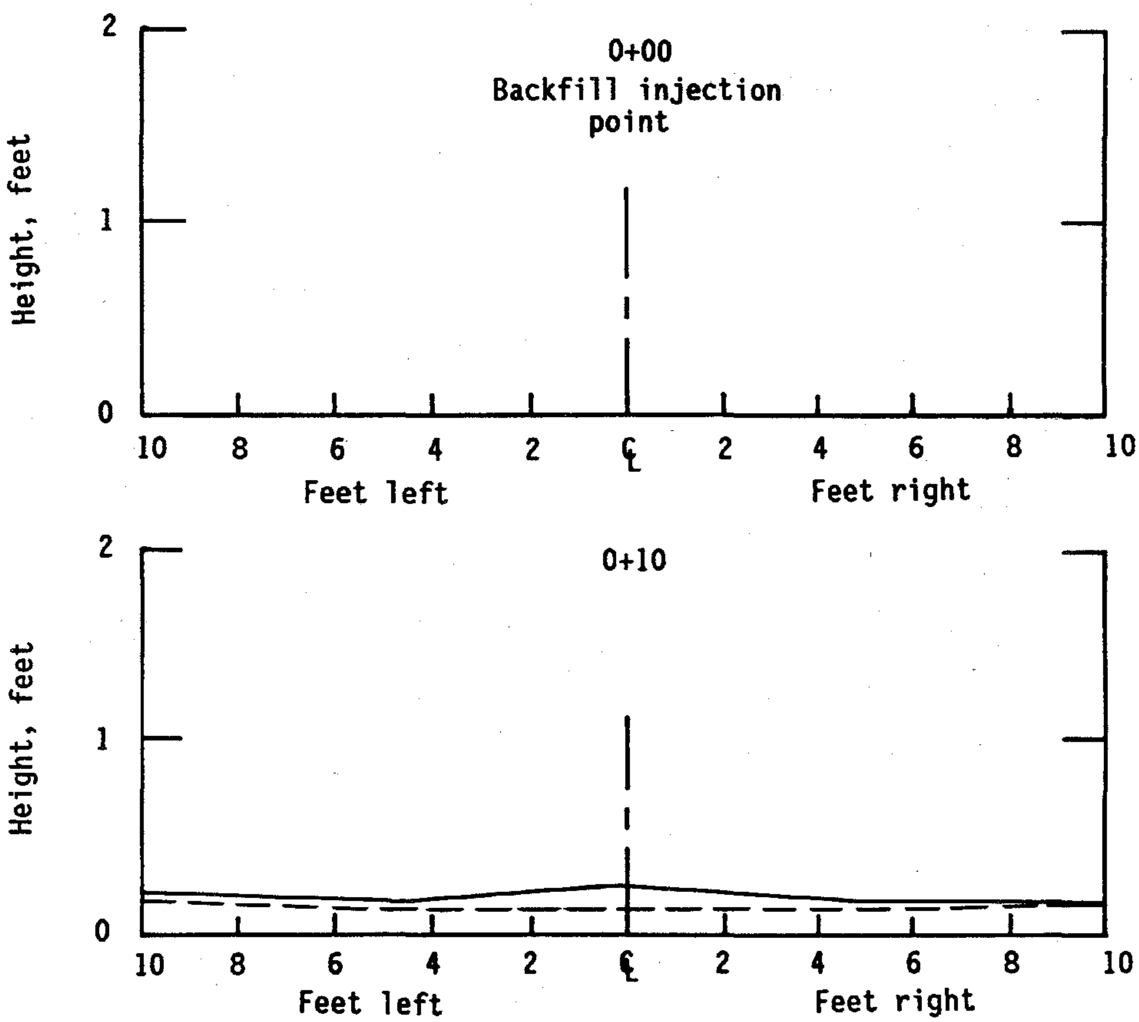


FIGURE 8. - **Beginning of backfill material cross sections.**

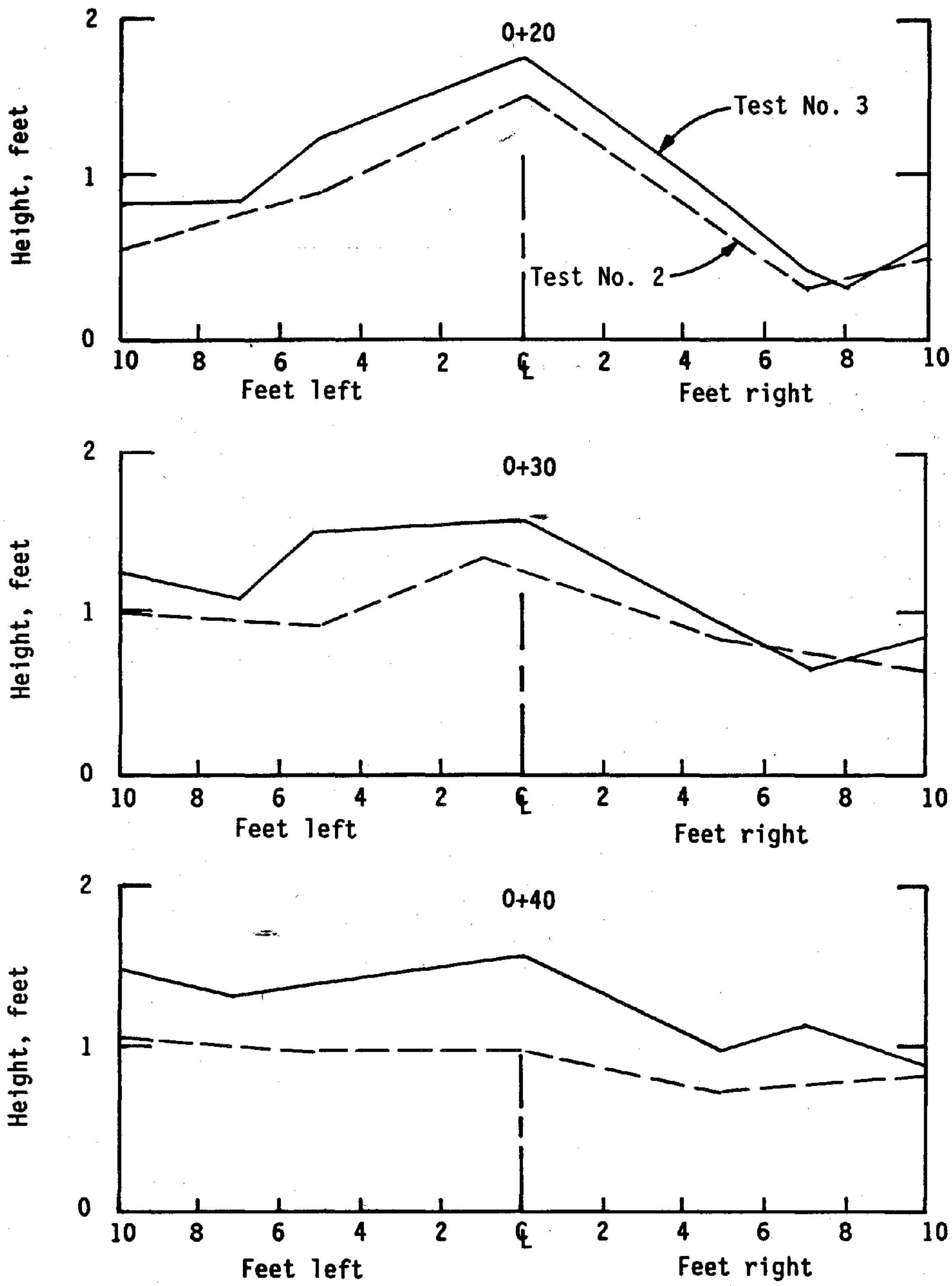


FIGURE 9. - Continued backfill material cross sections.

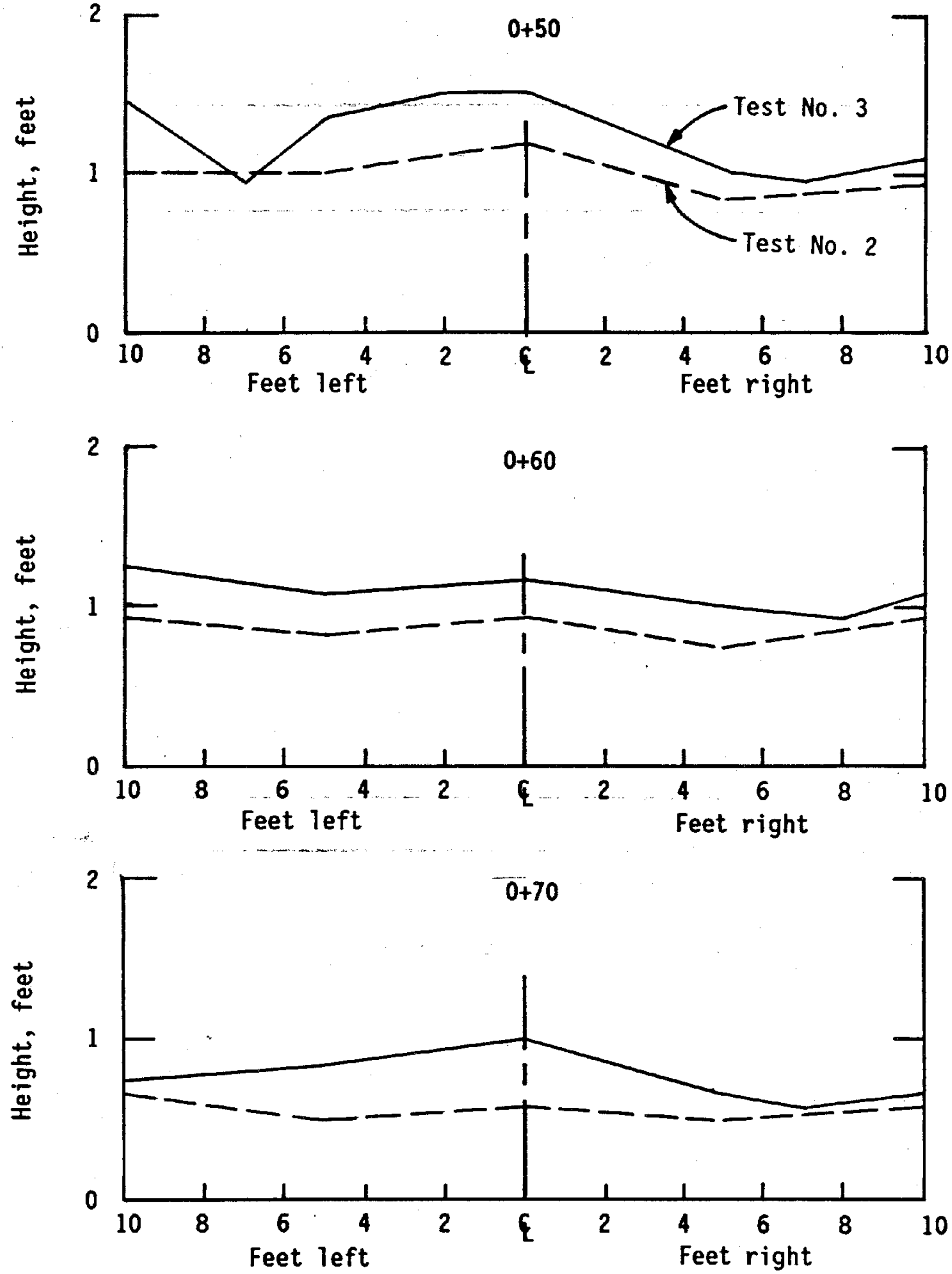


FIGURE 10. - Continued backfill material cross sections.

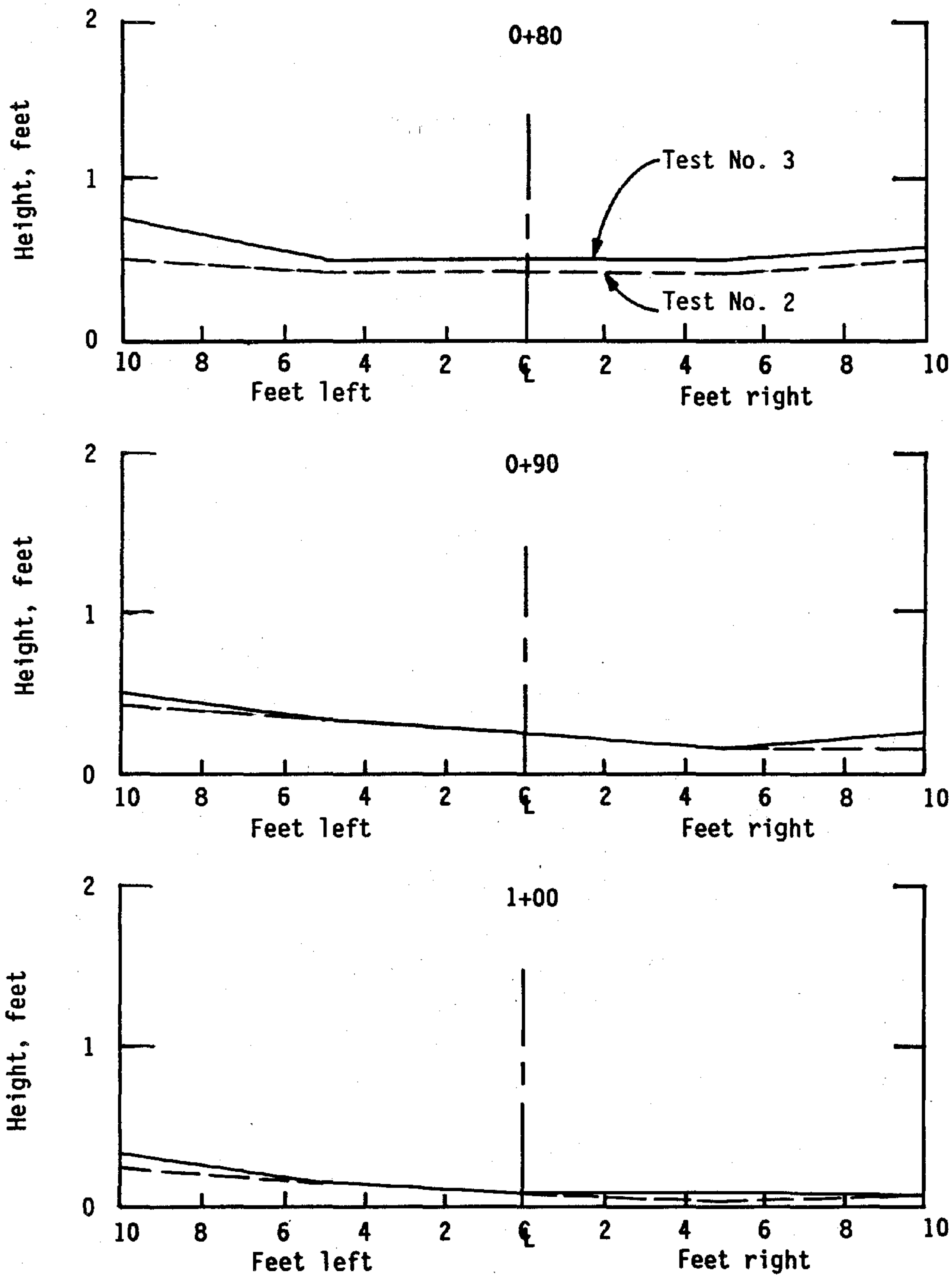


FIGURE 11. - End of backfill material cross sections.

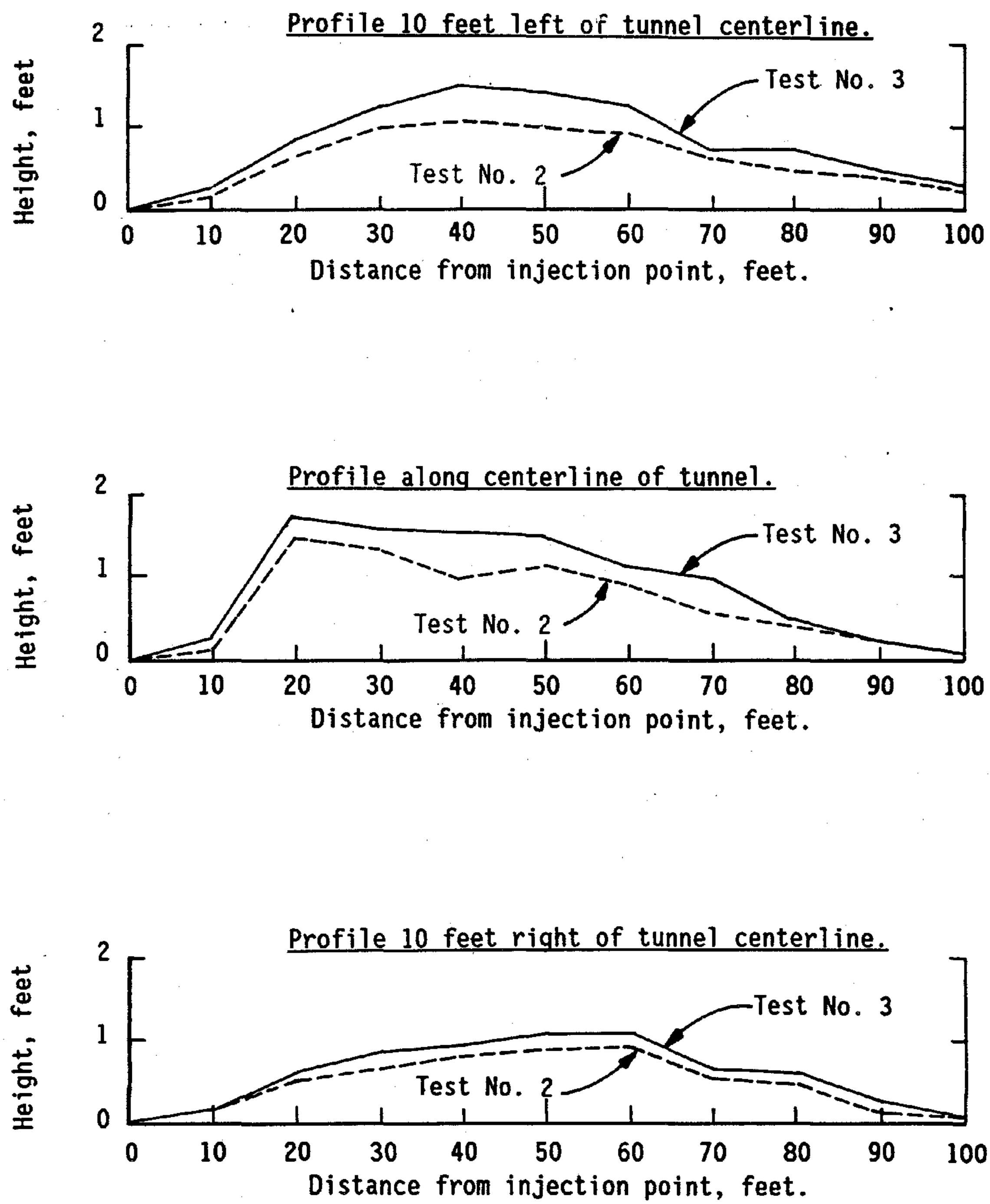


FIGURE 12. - Profiles of backfilled material within test tunnel.

TABLE 9. - Summary of backfill measurements.

Station	Test No. 2 Volume, cu yd	Test No. 3 Volume, cu yd	Difference (+/- cu yd)
0+00			
	0.50(1%)	0.74(1%)	+0.24
0+10			
	3.77(8%)	4.64(8%)	+0.87
0+20			
	6.88(15%)	8.35(15%)	+1.47
0+30			
	7.05(16%)	9.30(16%)	+2.25
0+40			
	7.10(16%)	9.34(16%)	+2.24
0+50			
	6.79(15%)	8.51(15%)	+1.72
0+60			
	5.16(12%)	6.96(12%)	+1.80
0+70			
	3.67(8%)	4.94(9%)	+1.27
0+80			
	2.52(6%)	3.05(5%)	+0.53
0+90			
	1.30(3%)	1.54(3%)	+0.24
1+00			
Total	44.74(100%)	57.36(100%)	+12.62

Total material stowed during test Nos. 1 and 2 = 44.74 cu yd.

Total material stowed during test 3 = 12.62 cu yd.

DISCUSSION AND SUMMARY

The test data obtained during this controlled testing situation was not as complete as originally intended. The inability to accurately control predetermined material feed rates, air flow, and moisture content by water injection prevented the development of performance curves. However, the tests still proved to be very informative and provided insight toward possible improvements to the system.

Overall, the stowing equipment performed as anticipated with an approximate stowing rate of nearly 30 tph. This stow rate was obtained using less than 1000 cfm. Material was projected to a maximum of 150 ft., however the majority of the material was stowed from 20 to 100 ft. from the injection point.

Wear (abrasion) was found to be a continuing problem as in the past. The aggregate within sample No. 8 material was found to be extremely abrasive and wore a hole in the barrel at about 40 cu yds of production. Design modifications are being considered which would allow for that amount of wear in the normal operation of the equipment.

In short, this system demonstrated the ability to perform in remote mine void conditions. This test, as well as past testing, has repeatedly proven the potential of the RAJPSS of remote pneumatic stowing to effectively place material within mine voids.

The optimum capacity of this system has not been determined as of this test period. Before the performance and capacity can be accurately determined, a number of modifications must be incorporated into the test site and the stowing equipment. The primary purpose of these modifications is to prevent the frequent plugging problems which occurred. Recommended modifications based on this testing period are as follows:

1. Incorporation of a screen to prevent oversized rocks from entering the borehole.

2. Ability to control a variable-speed feed mechanism at the borehole. The feed should be uniform and at a predetermined flow volume. The operator at the borehole needs to be able to select his rate according to the site conditions.

3. Additional air flow may substantially increase the capacity of this system.

4. The moisture content of the material should be further investigated. It appears that some relationship between performance and moisture content exists.

5. A broader range of aggregate gradation should be tested. The optimum size of material for a given air flow has not been determined.

6. Design modifications to the footpiece which would allow for abrasion without degrading normal operation of the equipment.

By incorporating these modifications, the true capacity of this stowing system can be more readily determined. Also, these modifications will allow continuous operation without plugging so that equipment wear can be further studied.

Based on our previous experience and our observation of this new equipment, we estimate that a 60 ft. length of the simulated mine void could be completely filled using the equipment developed for this investigation.

CONCLUSION

Past performance, personal observation, earlier testing, and the results of the current effort all substantiate the usefulness and effectiveness of the RAJPSS in filling voids. The system is the logical choice for filling mine workings with from 20 to 100 ft of overburden where the workings are mostly open and continuous. Further study may show greater depths of overburden would be in the cost-effective range also.

Virtually any type of backfill material can be stowed by this method, thereby allowing projects to utilize waste material or readily available local materials. Certain characteristics of backfill material limit stowing rates and increase chances for plugging. Much more study and testing of materials would allow for the development of guidelines for selection and stowing of various backfill materials. Further testing is necessary to develop other data which will enable further determination of the factors limiting the rate of backfill.

Recent tests show the present system is capable of stowing 30 tph with an air supply of 924 cfm at 125 psi.

Depending on the room heights, the equipment is capable of projecting material laterally more than 80 ft from the injection borehole. Analysis of test results indicates that a complete backfill of void up to 60 ft in length from one injection point can be performed with present equipment.

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