STOPPINGS FOR VENTILATING COAL MINES

By Edward M. Kawenski, Donald W. Mitchell,
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STOPPINGS FOR VENTILATING COAL MINES

by

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ABSTRACT

Tests were made in the Bureau of Mines Experimental Coal Mine on stoppings similar to those used in operating coal mines to obtain information on air leakage through the face and the rupture strength of a stopping subjected to a pressure differential. Block stoppings were made from cinder, slag, and gravel aggregates with and without mortared joints and coatings. Sheet stoppings were uncoated brattice cloth and nylon or brattice cloth and expanded-metal-lath coated with asphalt, latex, mortar, or rigid urethane foam. Limited data were obtained on air leakage through stoppings subjected to simulated roof convergence and to shock forces created by the firing of an adjacent charge of explosive. The pressure differential required to rupture stoppings was determined.

The research shows that coating the face of a stopping effectively reduces air leakage. Block stoppings, particularly those with mortared joints, are most resistant to pressure and shock forces than are sheet stoppings. Where ground movement is a factor, sheet stoppings leak less air than block stoppings.

INTRODUCTION

To assist in the design of effective ventilation systems, various materials and methods used in stopping construction were studied in the Bureau's Experimental Coal Mine. Stoppings are used to control and direct the flow of air through underground passageways and to seal off portions of a mine. Air leakage through stoppings increases the cost of providing sufficient air at the working face to dilute float coal dust and methane liberated during mining.

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In some coal mines, as little as 30 percent of the air induced by the fan on the surface reaches the working face;[5] the balance is short circuited through stoppings, doors, and overcasts.

Air leakage through a stopping depends on the pressure differential, the materials, method and care of construction, and on subsequent ground movement. Early studies by the Bureau of Mines discussed air leakage through mine doors,[6] through brattice-cloth curtains,[7] and through stoppings.[8] In a recent investigation, the effectiveness of brattice-cloth curtains in ventilating face areas was evaluated. Research was conducted at the Virginia Polytechnic Institute on air leakage through solid masonry materials.[9] Preliminary results of the present investigation were reported previously.[10]

TEST PROCEDURES

Air leakage determinations were made on stoppings newly constructed, deformed by ground movement or subjected to shock from explosive charges. A few trials were made in the laboratory on single block used in stopping construction. In all instances, air leaked only through the face of the stopping or block as the perimeter was effectively sealed with rubber gaskets, mortar, or urethane foam. In operating mines, considerable air may leak at the juncture of the stopping and the mine surfaces. Because this leakage depends on care and workmanship during construction, it was not studied in the present investigation. Data on air leakage are reported as cubic feet of air per minute per 100 square feet of stopping area. Comparative tests on stoppings 21 and 36 square feet in area showed that air leakage is directly proportional to the face area.

[5]Kingery, Donald S. Introduction to Mine Ventilating Principles and
    Practices. BuMines Bull. 589, 1960, 54 pp., see p. 22.
[6]Paul, J. W., G. E. McElroy, and H. P.Greenwald. Tests on the Leakage of
    Mine-Ventilating Doors. BuMines Rept. of Inv. 2602, 1924, 3 pp.
[7]Rice, G. S., and C.W. Owings. The Use of Brattice Cloth in Coal Mines.
    BuMines Rept. of Inv. 2872, 1928, 8 pp.
[8]Williams, R. Y. Mine-Ventilation Stoppings, with Especial Reference to Coal
    Mines in Illinois. BuMines Bull. 99, 1915, 30 pp.
[9]Holland, C. T., and L. Sargeant. An Investigation of Material Used for
    Stopping Construction in Coal Mine Ventilation Systems. Proc. Coal Min.
    Inst. America, Pittsburgh, Pa. 1958, pp. 60-80.
[10]Kawenski, Edward M., and Donald W. Mitchell. Rapid and Inexpensive Erection
    of Stoppings With Rigid Foam. Proc. Coal Min. Inst. America, Pittsburgh,
    Pa., Dec. 13-14, 1962, pp. 80-87.
    _____. An Evaluation of Stopping Construction. Paper presented at 1963 Coal
    Conv., Am. Min. Cong., Pittsburgh, Pa., May 5-8, 1963, 12 pp.
    _____. Evaluation of Materials for Ventilation Structures. Paper presented
    at 1965 Coal Conv., Am., Min. Cong., Pittsburgh, Pa., May 9-12, 1965, 8 pp.
  Mitchell, Donald W. A New Rigid Foam for Stoppings and Sealing Mine Ribs
    and Roof. Paper presented at 52nd Ann. Conv. Mine Inspectors' Inst.
    America, Springfield, Ill., June 11-13, 1962, 8 pp.

The air pressure required to crack or burst several types and sizes of stoppings was determined. This characteristic of stoppings is subsequently referred to as its rupture strength. Details of the several test arrangements are given below.

Air Leakage Through the Face of a New Stopping

Figure 1 shows the general arrangement for determining the air leakage through the face of a newly constructed stopping. The stopping formed one wall of a 900-cubic foot chamber (a sealed cut-through). Compressed air was forced into the chamber. The measured rate of air input required to maintain a given pressure differential across the stopping equals the rate of air leakage through the stopping. The test arrangement for a wet-wall,[11] cinder-block stopping is shown in figure 2. For high rates of leakage, flow meters were used to measure the air; at low rates the wet-gas meter illustrated in the picture was used. The manometer for measuring the pressure differential was connected to a tube passing through the framework.
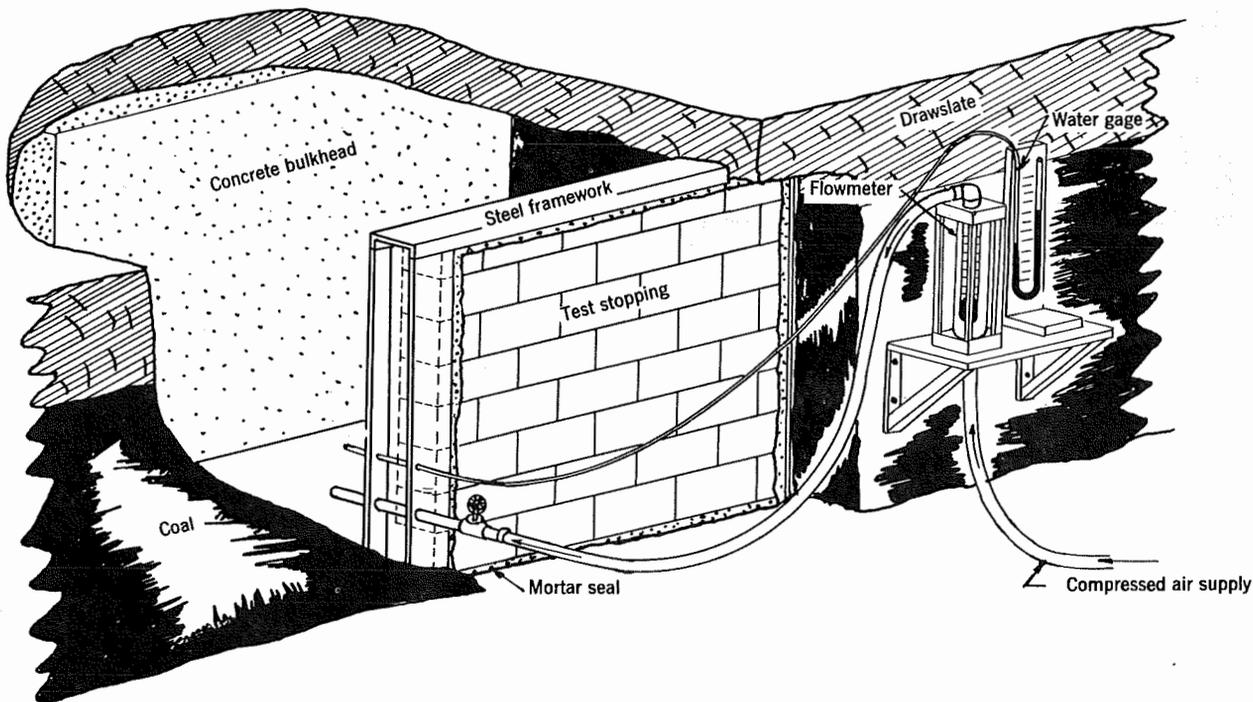
FIGURE 1. - Arrangement for Determining Air Leakage Through the Face of a Newly Constructed Stopping.

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[11]A wet wall stopping is made with mortar between the joints of the block; a dry wall stopping is made of blocks without mortar between the joints.

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FIGURE 2. - Cinder-Block Stopping Prepared for Test of Air Leakage.

The air leakage through a single block was investigated in the laboratory.
As shown in figure 3, the arrangement is similar to that used in the mine
tests. The block was sealed in a steel box; one face was exposed. Compressed
air flowed at a measured rate into the box behind the block. Air leakage
through the block is illustrated by the air bubbles formed from a soap solution
coating.

<u>Air Leakage Through the Face of a Stopping Deformed</u>
<u>by Simulated Strata Convergence</u>

In many coal mines, convergence of roof and floor deforms a stopping
causing it to leak air. In our experiments, convergence was simulated by
forcing a portion of a block stopping into a yielding roof. As shown in
figure 4, three hydraulic rams bear on a steel beam at the bottom and across
one-half the width of the test stopping. Shear stresses develop as the stop-
ping is forced into the roof. The effect of roof yield was studied by capping
the stopping with cement-vermiculite mixtures having compressive strengths of
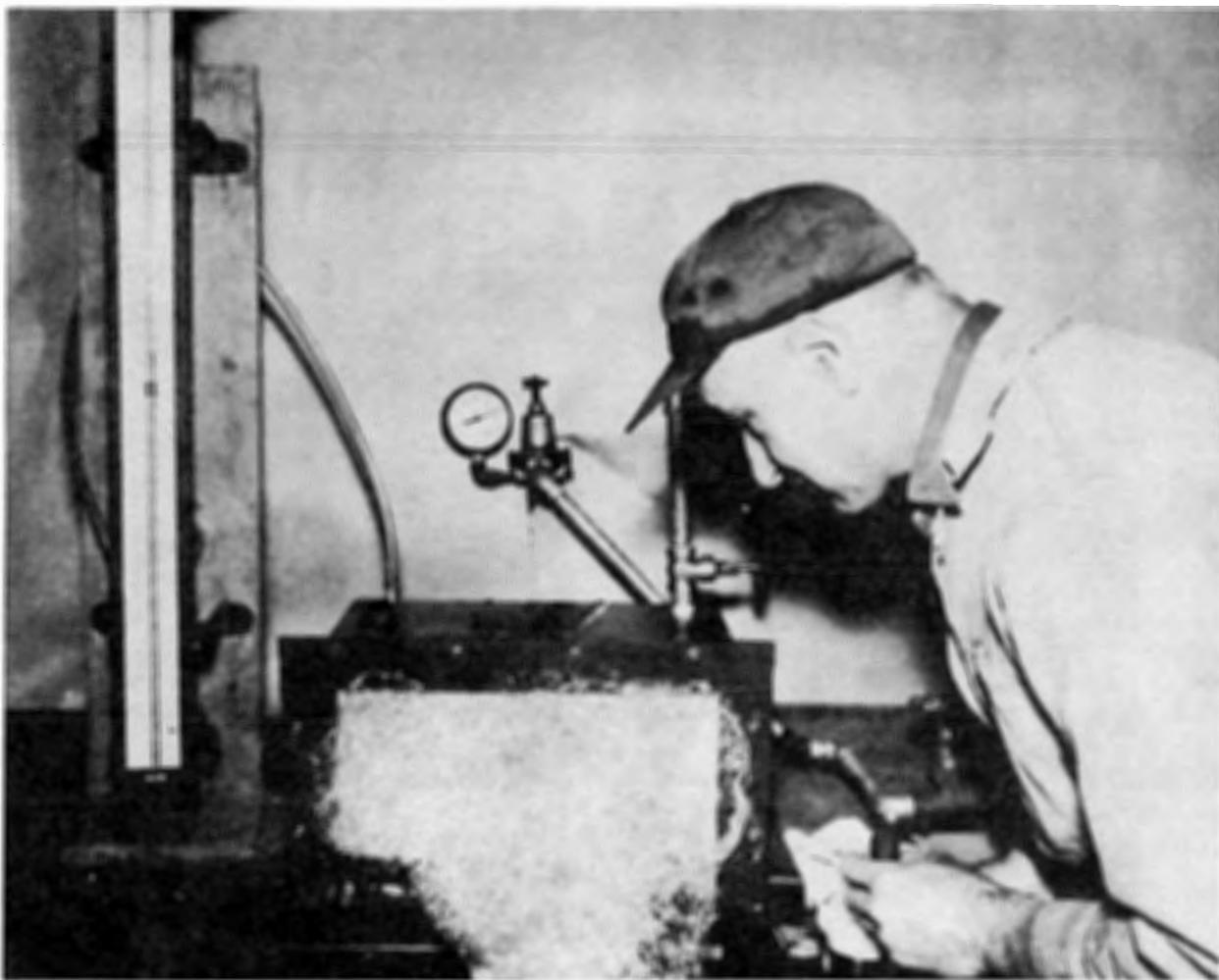
FIGURE 3. - Laboratory Air-Leakage Test on a Single Block.

300 and 2,000 psi. The cinder-block also had a compressive strength of 2,000 psi. The stopping, 2.9 feet high and 7.1 feet wide, was constructed as one wall of the 180-cubic-foot chamber. The perimeter of the stopping and the bottom steel plate were sealed and air leaked through the face.

A few trials were made to determine the vertical movement required to crack a 1-inch thick, foam-covered brattice-cloth stopping (fig. 5). The bottom of the brattice cloth was attached to a 1-1/2- by 1-1/2- by 1/8-inch angle iron which was forced upward in the center by a single hydraulic ram. The ends of the angle iron were held in slots at each rib to permit lateral movement. A rubber apron was attached between the angle iron and the bottom framework to prevent air leakage at this juncture when the angle iron was deflected.

The vertical distance of ram movement was the measure of convergence. The amount of convergence occurring before the air leakage becomes excessive represents the ability of a stopping to withstand deformation.

FIGURE 4. - Mortar-Coated, Dry-Wall, Cinder-Block Stopping Subjected to Compressive Load.

FIGURE 5. - Method for Applying Vertical Load on Foam-Covered, Brattice-Cloth Stopping.

Air Leakage Through a Stopping Subjected to Shock From an Explosive Charge

Air leakage data were obtained on block and foam-coated brattice-cloth stoppings subjected to shock forces from the firing of an adjacent suspended charge of explosive. As shown in figure 6, a stopping 2.9 feet high and 7.1 feet wide was constructed in an opening in one rib of a dead-end entry. The stopping was built in one wall of a 180-cubic-foot chamber abutting the dead-end entry. An unconfined charge of permissible explosive was hung in the entry 6 feet from the geometric center of the stopping. The charge weight was increased in increments until the stopping failed.

Detonation of the suspended charge imposed dynamic forces on the stopping by energy released from the explosive and transmitted through the intervening air, by reflection from mine surfaces and by ground movement. Stress measurements on the stopping were not made. Data from these experiments indicate only the relative resistance of stoppings to these forces.

Rupture Strength of a Stopping

Most of the rupture-strength experiments were made on stoppings 6 feet high ranging from 3 to 16 feet in width, sealing a 500-cubic-foot chamber; a few trials were made on a 2.9- by 7.1-foot stopping. Pressure was developed by burning a black-powder charge in the chamber. Generally the charge weights were increased in increments until the stopping failed or until excessive air leakage occurred as determined by test; a few trials were made with a single-charge weight sufficient to cause rupture.

For the rupture-strength tests, the four edges of a sheet stopping were attached firmly to a wooden frame. The frame, constructed of 8-inch wide oak timber, 3 inches thick, was set in mortar and anchored by roof bolts to the mine surfaces or bolted to a steel frame. Brattice cloth was attached to the frame by wrapping it around furring strips 1-3/4 inches wide by 3/4 inch thick. The furring strips were attached to the oak timbers by 10-penny box nails on 4-inch centers. Nylon was attached by driving nails through the holes of metal grommets on 6-inch centers. Metal lath was attached to the outer edge of the oak timbers by furring strips.

Block stoppings were constructed in the oak frame also. For dry-wall stoppings, wooden wedges were driven between the top blocks and the oak timber; the gap at the top was filled with mortar. Mortar was also placed between the blocks and oak timber at the sides and bottom. Wet-wall block stoppings were constructed similarly, but wedges were not used at the top.

MATERIALS USED IN THE RESEARCH

The following materials were used to construct the test stoppings:

1. Hollow-core masonry block having dimensions of 8 by 8 by 16 inches. These blocks were made from gravel, cinder, or slag aggregate combined with sand and cement. Limited trials were made also on a gravel block, 6 by 8 by 16 inches, to which 2-1/4-percent fly ash by weight was added.

Coal face

13'11''

Reinforced
concrete

4'10''

A   A'

7'1''

Suspended
charge

Test
stopping

4'' I-beams on top
and sides

PLAN VIEW

Suspended
charge

3'3''

2'9''

4'9''

8'4''

6'

3'3''

0.625'' steel plate

SECTION A-A'

0   2   4   8

Scale, feet
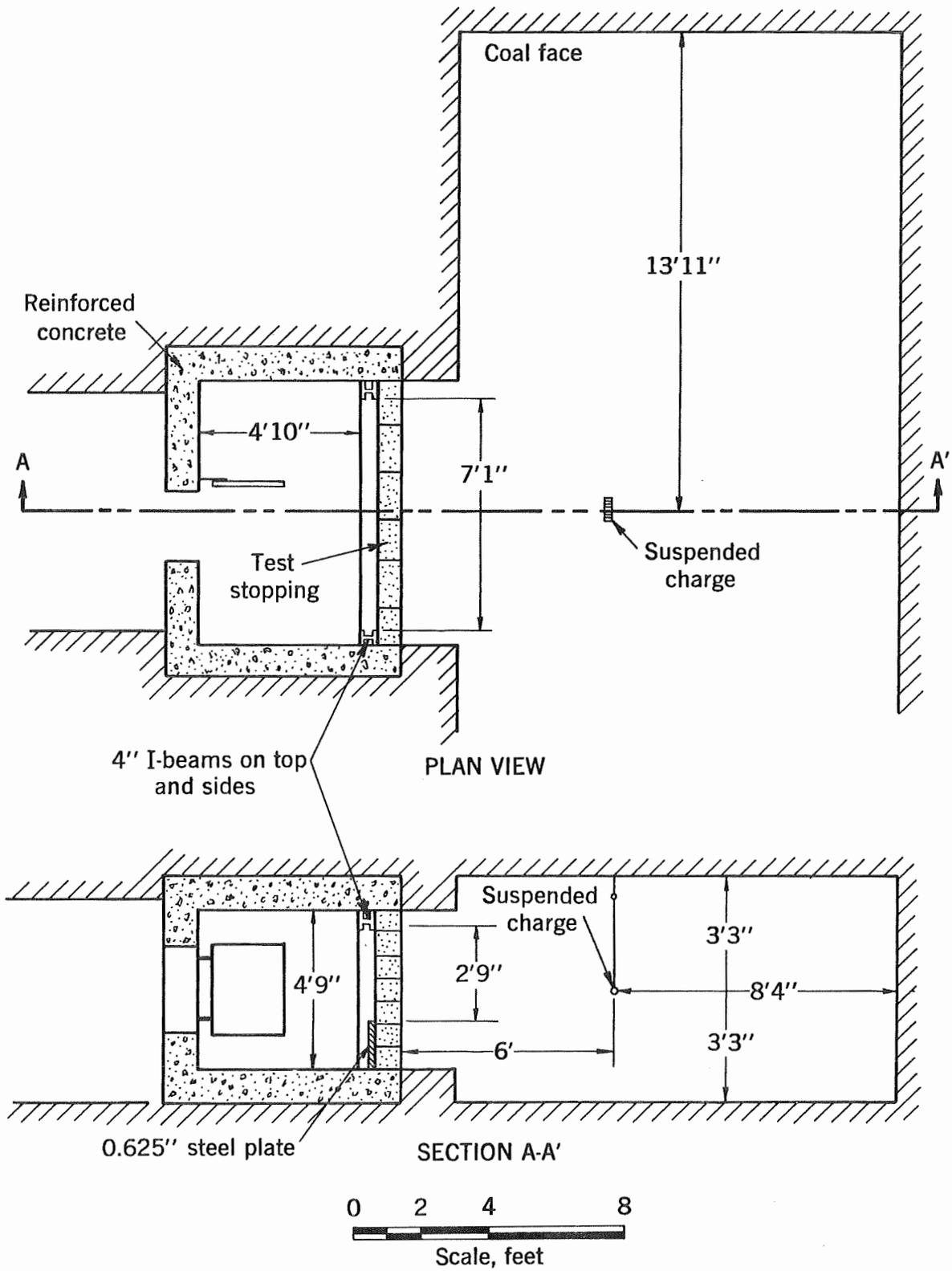
FIGURE 6. - Arrangement for Firing Suspended Charge Adjacent to Stopping.

2. Solid-concrete block (8 by 8 by 16 inches) made with a sand-gravel aggregate.

3. Brattice cloth (jute) weighing 14 ounces per square yard.

4. Expanded metal lath weighing 2.5 pounds per square yard and having 1/4-inch diamond-mesh openings (fig. 7).

5. Nylon-reinforced plastic sheet having a thickness of 20 mils.

6. Mortar made from 1 part high-early-strength cement, 2 parts sand, and 0.8 part water. This mortar was used between blocks in wet-wall construction and as a sealant on the face of stoppings (fig. 8).

7. Sealants of mortar, rigid-urethane foam, masonry paint, latex, and asphalt emulsion.

FIGURE 7. - Urethane Foam Being Applied to Metal Lath.

FIGURE 8. - Mortar Coating on a Dry-Wall, Cinder-Block Stopping.

8.   Black blasting powder, FFF grade.

9.   A nongelatinous permissible explosive having a rate of detonation of 8,900 feet per second.

Spray-applied urethane foam had a nominal thickness of 1 inch. Mortar coatings were 1/4- to 1/2-inch thick. The masonry paint, a commercial product obtained in powdered form and mixed with water, was applied by a brush as two 20-mil-thick coats. The latex was brush-applied as a single coat about 1/8-inch thick. The asphalt emulsion, a proprietary compound containing asbestos fines, was applied 1/8-inch thick by a spray gun. All sealants were applied to the low-pressure side of the stopping.

RESULTS

Air Leakage Through the Face of a New Stopping

For all stoppings tested, air leakage increased with the pressure differential according to the formula:

$$Q = a P^n \tag{1}$$

where Q is air leakage in cubic feet per minute per 100 square feet of stop-ping area, P is the pressure differential (inches of water) and a represents the air leakage at a pressure differential of 1-inch water gage, and is a function of the stopping material and method of construction; its numerical value ranged from 5 for coated and nylon stoppings to 35,000 for uncoated brattice cloth. The exponent n is reportedly[12] related to the turbulence in the air passing through the crevice. In three instances its value was less than 0.5. Theoretically, for air flow through porous materials, this exponent should range between 0.5 and 1.0.

The data shown in figure 9 for air leakage through dry- and wet-wall, cinder-block stoppings are typical of those obtained in our experiments. Values of a and n are given in table 1 for each of the materials studied; when substituted in equation (1), the air leakage for a given pressure differential can be estimated.
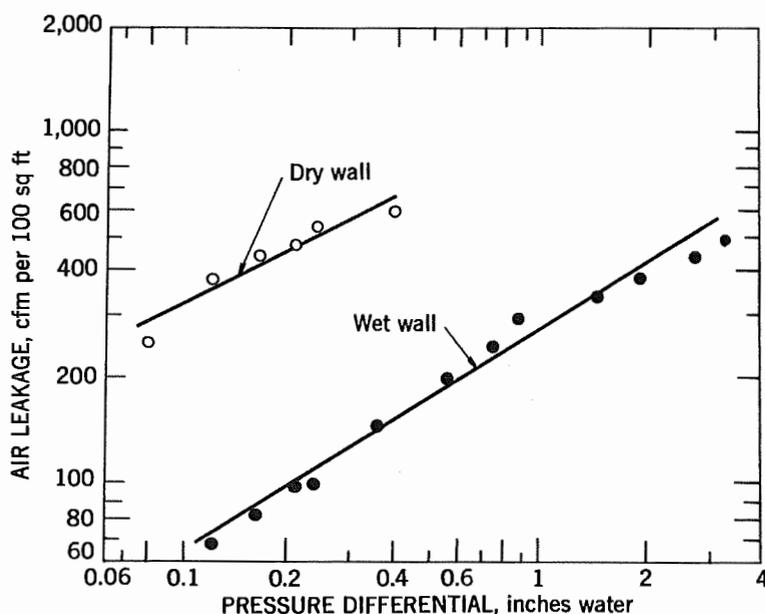
FIGURE 9. - Air Leakage Data for Wet- and Dry-Wall, Cinder-Block Stoppings.

Repetitive trials were made to determine the repro-ducibility of data on air leakage. Seven 6- by 6-foot hollow-core, wet-wall, cinder-block stoppings were tested. The value of the constant a ranged from 185 to 280 cubic feet per minute (cfm) and averaged 215 cfm; the coefficient of variation is 15 percent. The value of the exponent n ranged from 0.62 to 0.69, averaging 0.66; the coefficient of variation is 4 percent. In our study, air leakage for the hollow-core, cinder-block stopping is reported as 280 cfm for wet-wall and 1,060 cfm for dry-wall construction. In previous research by Holland,[13] air leakage for comparable stoppings was of the same order of magnitude, being 225 and 1,250 cfm, respectively.

Air leakage data are given in this report for a pressure differential of 1-inch water gage. The relative values of air leakage through stoppings listed in table 1 would be different at lower or higher pressure differen-tials. For example, at a 1-inch water gage, the air lost through a wet-wall, cinder-block stopping is 30 percent of that lost through a similar dry-wall stopping, whereas at 5 inches water gage, it is 50 percent.

[12]Leva, M., M. Weintraub, M. Grummer, M. Pollchick, and H. H. Storch. Fluid Flow Through Packed and Fluidized Systems. BuMines Bull. 504, 1951,149 pp.
[13]Work cited in footnote 9.

TABLE 1. - Air leakage coefficients and exponents
for newly constructed mine stoppings

Line No.	Stopping construction	Coefficient, a	Exponent, n
	Cinder block		
1	Hollow core, dry-wall............................	1,060	0.5
2	Hollow core, dry-wall, mortar-coated.............	5	.9
3	Hollow core, dry-wall, foam-coated...............	5	.9
4	Hollow core, dry-wall, masonry paint.............	10	.8
5	Hollow core, dry-wall, latex-coated..............	10	.9
6	Hollow core, wet-wall............................	280	.7
7	Hollow core, wet-wall, mortar-coated.............	5	.9
8	Hollow core, wet-wall, foam-coated...............	5	1.0
	Slag block		
9	Hollow core, dry-wall............................	1,400	0.3
10	Hollow core, dry-wall, mortar-coated.............	5	.9
11	Hollow core, dry-wall, foam-coated...............	10	.8
12	Hollow core, wet-wall............................	340	.7
13	Hollow core, wet-wall, mortar-coated.............	5	.9
14	Hollow core, wet-wall, foam-coated...............	5	1.0
	Gravel block		
15	Hollow core, dry-wall............................	900	0.3
16	Hollow core, dry-wall, mortar-coated.............	5	.9
17	Hollow core, dry-wall, foam-coated...............	10	.8
18	Hollow core, wet-wall............................	55	.8
19	Hollow core, wet-wall, mortar-coated.............	5	.9
20	Hollow core, wet-wall, foam-coated...............	15	.8
21	Solid, dry-wall..................................	1,200	.9
22	Solid, dry-wall, mortar-coated...................	5	.9
23	Solid, dry-wall, foam-coated.....................	5	1.0
24	Solid, wet-wall..................................	20	.9
25	Solid, wet-wall, mortar-coated...................	5	1.0
26	Solid, wet-wall, foam-coated.....................	5	1.0
	Fly-ash block[1]		
27	Hollow core, wet-wall............................	25	0.7
	Sheet stoppings		
28	Brattice cloth...................................	35,500	0.7
29	Brattice cloth, foam-coated......................	5	1.0
30	Brattice cloth, latex-coated.....................	10	.8
31	Brattice cloth, 1 coat of asphalt................	40	.7
32	Brattice cloth, 2 coats of asphalt...............	20	.8
33	Metal lath, mortar-coated........................	15	.4
34	Metal lath, foam-coated..........................	5	1.0
35	Nylon..	5	1.0

[1] 6- by 6- by 18-inch block; all others 8- by 8- by 16-inch.

Block Aggregate

The aggregate used in block manufacture affects air leakage. Block with gravel aggregate is more resistant to air leakage than block with cinder or slag aggregate. For example, leakage through a hollow-core, wet-wall block stopping was 55 cfm with gravel, 280 cfm with cinder, and 340 cfm with slag aggregate (table 1). Air leakage through the gravel block was reduced from 55 cfm (line 18) to 25 cfm (line 27) when fly ash was added to the aggregate.

Block Form

The block form affects air leakage for wet-wall construction; air leaks through solid block less rapidly than it does through hollow-core block. This is shown in table 2 for gravel-aggregate block in a wet-wall stopping. Air leakage is 20 cfm for the solid and 55 cfm, or 2.7 times greater, for the hollow-core block.

Data in table 2 also show that air leakage through a dry-wall stopping is relatively unaffected by block form. The solid-block stopping leaks 1,200 cfm, and the hollow-core block slightly less, or 1,060 cfm. Air flows primarily through open joints between blocks and the solid block had a rougher surface of contact.

TABLE 2. - Air leakage through block stoppings

Block aggregate and form	Air leakage, cfm	
	Wet wall	Dry wall
Gravel, solid..............	20	1,200
Gravel, hollow core.......	55	900
Cinder, hollow core.......	280	1,060
Slag, hollow core.........	340	1,400

Block-Stopping Construction

Data in table 1 show that wet-wall construction is superior to dry-wall construction. For the several types of block studied, the air leakage through the wet-wall stopping was one third or one sixtieth as much as that through the dry wall.

Sheet Stoppings

Air leakage through uncoated brattice cloth was 35,500 cfm or 25 times more than that through the poorest block stopping tested. Leakage through the face of nylon cloth was less than 5 cfm, which is comparable to that through coated block.

Coated Stoppings

Air leakage can be reduced by sealing the stopping. With coatings of mortar, masonry paint, latex and urethane foam, air leakage was 5 to 15 cfm.

Although the asphalt coating was not quite as effective a sealant as the other materials, it reduced the leakage through the stopping considerably. Air leakage was 40 cfm with one and 20 cfm with two coats of asphalt. The type of block aggregate, block form, or presence of mortar in the joints of a stopping do not affect air leakage through a coated stopping.

Air Leakage Through a Single Block

Data in table 3 show that for equivalent areas, air leakage through the single cinder and slag blocks is about half of that through the wet-wall block stopping. Less air also leaked through the single concrete block than through the wet-wall stopping. The converse was true for the gravel block with fly ash; this deviation in trend is believed due to the use of different lots of block. The original lot of fly ash, gravel block was not avilable when air-leakage trials were made in the laboratory. The greater air leakage through the wet-wall stoppings than through the single blocks is attributed to leakage at the joints. This emphasizes the importance of minimizing leakage at the joints in practice by using quality ingredients and good workmanship in laying blocks.

The mathematical relation between air leakage and pressure differential for single block is the same as that for stoppings, equation (1). Single blocks made with gravel aggregate leaked less air than those made with cinder or slag aggregates. The solid block (gravel aggregate) leaked less air than a similar hollow-core block.

TABLE 3. - Comparison of air leakage through a single-block and a wet-wall mine stopping

Type of block	Air leakage, cfm/100 sq ft		Exponent, n	
	Single block[1]	Wet-wall stopping	Single block[1]	Wet-wall stopping
Cinder, hollow core........................	140	280	0.6	0.7
Slag, hollow core.........................	150	340	.7	.7
Gravel, hollow core.......................	40	55	.7	.8
Gravel, solid.............................	5	20	.9	.9
Gravel with fly ash,[2] hollow core.........	40	25	.7	.7

[1] Average value from two tests.
[2] 6- by 8- by 16-inch block; all others 8- by 8- by 16-inch.

Air Leakage Through the Face of a Stopping Deformed by Simulated Strata Convergence

The data for air leakage and convergence of cinder-block and brattice-cloth stoppings subjected to nonuniform loading are given in table 4. For the soft roof strata, the convergence of the cinder-block stoppings, when leakage became excessive, was about 1-1/2 inches in trials with coated or uncoated stoppings and with wet- or dry-wall construction. When capped with hard strata, the convergence required to create excessive air leakage was one-third inch for these stoppings. The loads required to produce this convergence were

greater for the hard roof and for wet-wall construction than for the soft roof and for dry-wall construction. Coatings on stoppings have no appreciable effect on the maximum convergence or load sustained by the block stoppings. The foam-covered stoppings leaked less air than the mortar- or latex-coated-block stopping subjected to the same convergence. As shown in figure 4, most of the mortar coat has cracked and spalled from the cinder-block stopping at failure.

TABLE 4. - Effect of roof-floor convergence on air leakage through 2.9-foot high cinder-block and brattice stoppings

Stopping	Load, tons	Convergence, inches	Air leakage,[1] cfm
Simulated soft strata			
Cinder, dry-wall, uncoated.................	45	1.4	1,700
Cinder, dry-wall, foam-coated..............	55	1.6	140
Cinder, dry-wall, latex-coated.............	50	1.6	960
Cinder, dry-wall, mortar-coated............	40	1.1	700
Cinder, wet-wall, uncoated.................	65	1.8	600
Brattice cloth, foam-coated................	(2)	5.0	8
Simulated hard strata			
Cinder, dry-wall, uncoated.................	40	0.7	900
Cinder, dry-wall, foam-coated..............	75	.3	240
Cinder, dry-wall, latex-coated.............	65	.4	360
Cinder, dry-wall, mortar-coated............	70	.4	550
Cinder, wet-wall, uncoated.................	130	.3	360

[1]Air leakage when stopping was considered to have failed.
[2]Load less than 1 ton.

The foam-coated brattice cloth withstood a convergence of 5 inches before appreciable air leakage occurred. This stopping would not support the roof. The appearance of this stopping at failure is shown in figure 5.

Air Leakage Through a Stopping Subjected to Shock
From an Explosive Charge

In tests made with a suspended charge of explosive fired adjacent to the stopping, the air leakage increased only slightly when charge weights less than that required for rupture were fired (table 5). As the stoppings were not resealed between trials, the air leakage values represent the cumulative effects of the shots. A foam-covered brattice ruptured when the charge weight was 0.84 pound. A charge weight three times greater was required to rupture a mortar-covered, dry-wall, hollow-core, cinder-block stopping. For the 1-1/4- by 8-inch explosives used, two cartridges were required to rupture the brattice cloth and six cartridges for the block stopping (2.9 by 7.1 feet).

TABLE 5. - <u>Air leakage through stopping subjected to shock from an explosive charge</u>

Charge weight, lb	Air leakage, cfm/100 sq ft	Exponent, n
Mortar-coated cinder block		
0	5	0.7
.84	14	.7
1.72	29	.7
2.52	(1)	-
Foam-coated brattice		
0	2	0.7
.20	2	.7
.42	3	.8
.63	9	.9
.84	(2)	-

[1] Blocks dislodged.
[2] Foam ruptured and brattice cloth tore.

<u>Rupture Strength of a Stopping</u>

When a stopping was subjected to a pressure pulse from the burning of black powder, the air leakage was relatively unaffected when pressures were insufficient to cause rupture (table 6). For both dry-wall cinder block, and foam-coated brattice-cloth stoppings, the air leakage coefficient and exponent (equation (1)) were relatively unaffected. Air leakage through the cinder-block stopping decreased slightly on the third trial (0.88-pound charge) because dust was blown into the crevices of the stopping when the black powder burned.
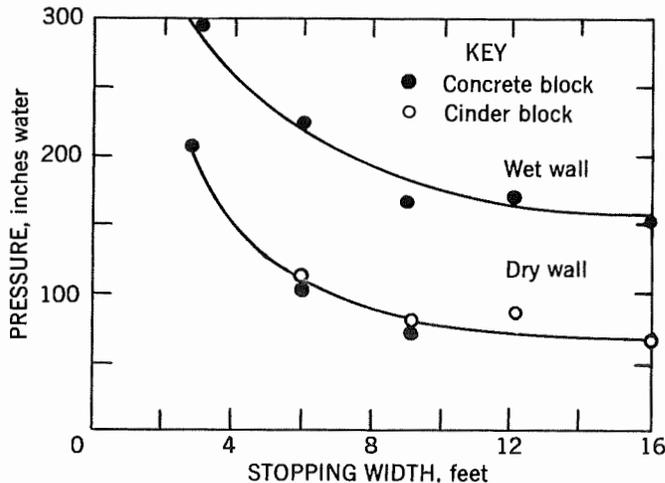

FIGURE 10. - Pressure Differentials Required to Rupture Dry-Wall and Wet-Wall Block Stoppings (6 Feet in Height).

Data on the pressure required to rupture 6-foot high, hollow-core, block stoppings are shown graphically in figure 10. A wet-wall stopping withstood about two times more pressure than a dry wall. The pressure required for rupture decreased with increase in stopping width. For the wet wall, the pressure decreased from 300 inches of water for a 3-foot width to 155 inches for a 16-foot width. For the dry wall, the respective pressures for the 3- and 16-foot widths are 210 and 70 inches of water, respectively.

The rupture strength of a sheet stopping appeared to be independent of base material, type of coating and stopping width. On the average, the 6-foot high stoppings ruptured at 20 inches of water. Data for

the rupture tests in which the charge weights were successively increased are given in table 7. Except for the 16-foot wide, foam-coated brattice cloth, the use of 4-inch diameter post supports on 4-foot centers did not materially affect the pressure required for rupture. In the noted exception, a higher pressure was obtained in the test with the post supports; however, the pressure for rupture when no post supports were used is considered abnormally low. In all instances, one or more of the posts were dislodged during the test; it was not possible to prevent this using normal procedures for wedging the posts in place.

TABLE 6. - Air leakage through 2.9- by 7.1-ft stoppings subjected to pressure from burning black powder

Charge weight, lb	Air leakage, cfm	Exponent, n
Dry-wall, cinder block		
0	1,250	0.58
0.44	1,400	.58
.88	950	.37
1.32	(1)	(1)
Foam-coated brattice cloth		
0	5	0.70
0.044	6	.70
.066	7	.84
.110	(1)	(1)

[1] Stopping blown out.

Four tests were made with a single-charge weight of black powder sufficient to rupture a stopping. These were a 12-foot wide, unsupported brattice cloth, a 16-foot wide supported brattice cloth, a 16-foot wide unsupported metal lath, and a 16-foot wide supported nylon stopping. All stoppings except the nylon were foam covered. The respective pressures for rupture were 25, 18, 20, and 22 inches of water. On the average, the pressures for rupture with the single charge were 22 percent higher than those for the trials with successive charges.

TABLE 7. - Pressure required to rupture stoppings (6 feet high)

Stopping type/width, feet	Pressure, inches of water[1]				
	3	6	9	12	16
Brattice, foam-coated, unsupported	20	-	-	26	13
Brattice, foam-coated, supported	-	26	25	24	21
Metal lath, foam-coated, supported	[2]20	-	-	20	18
Nylon, unsupported	-	-	-	-	16
Nylon, supported	-	-	-	19	17
Block, dry-wall	210	105	80	90	70
Block, wet-wall	300	230	170	175	160

[1] Pressure in inches of water x 0.036 = pressure in pounds per square inch.
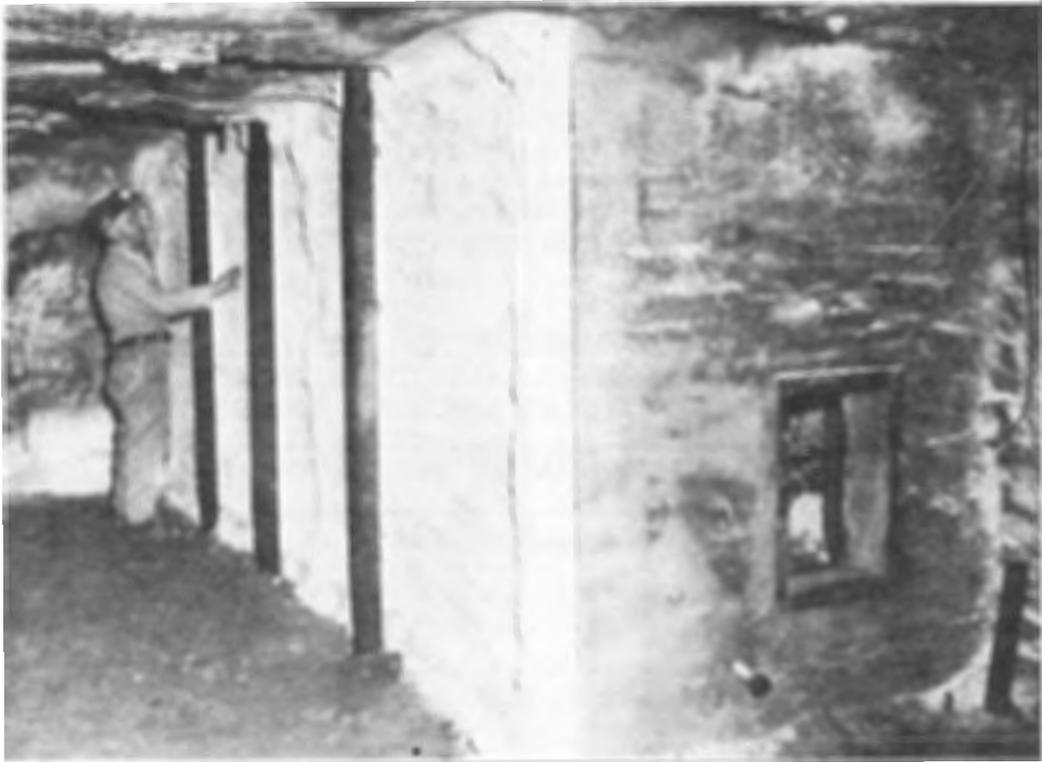[2] The same pressure ruptured a mortar-coated, metal-lath stopping.

FIGURE 11. - Foam-Covered Brattice-Cloth Stopping Prior to Rupture Test.

FIGURE 12. - Foam-Covered Brattice-Cloth Stopping After Rupture Test.

FIGURE 13. - Foam-Covered Metal-Lath Stopping After Rupture Test.

FIGURE 14. - Dry-Wall Block Stopping After Rupture Test.

Sheet stoppings greater than 9 feet in width failed by tearing rather than by frame failure. On stoppings 6 and 9 feet wide, with pressures approaching 20 inches water gage, the framework failed rather than the stopping. Figures 11 and 12 show a 16-foot wide, post-supported, foam-covered, brattice-cloth stopping before and after a test. Figure 13 shows a 16-foot wide, post-supported, foam-covered metal-lath stopping that ruptured at 20 inches of water pressure. For the block stoppings, the high pressure developed by the burning black powder dislodged and broke the block (fig. 14).

Typical pressure-time records for a cinder-block stopping are shown in figure 15. Data are shown for a test in which the pressure was insufficient to cause failure and for a test when failure occurred. The rate of pressure rise developed by the burning of the black powder ranged from 1 to 340 psi per second; the rate was affected by the charge weight and by leakage through the stopping.
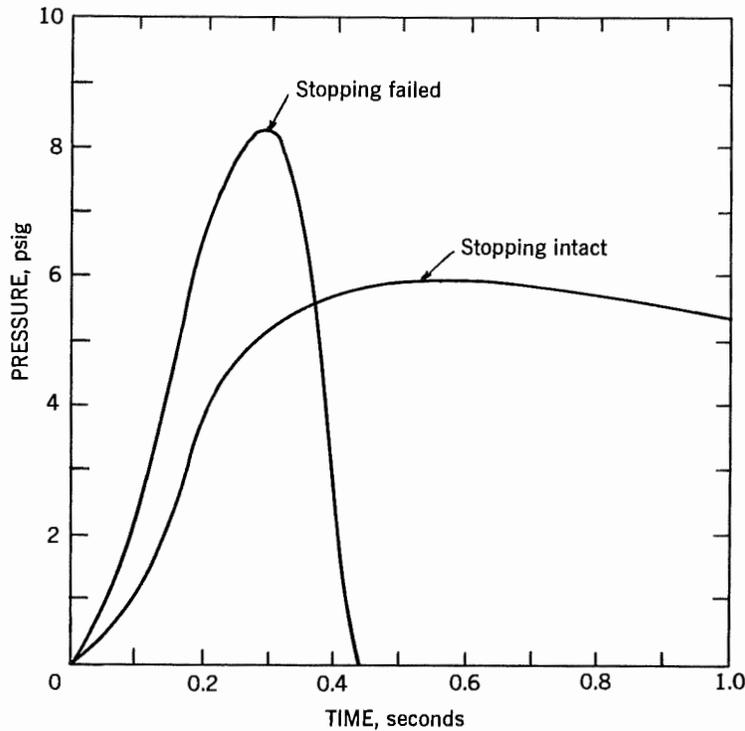
FIGURE 15. - Pressure Development in the 500-Cubic Foot Chamber by Burning Black Powder Confined by a 6- by 6-Foot Wet-Wall, Concrete-Block Stopping.

DISCUSSION

The research shows that no single type of stopping is superior to others for all the conditions encountered in coal mining. Where a stopping may be subjected to relatively high-pressure differentials, a foam-coated, wet-wall block stopping had the lowest air leakage and highest rupture strength. Where heaving bottoms and roof-floor convergence occurs, the foam-coated brattice cloth stopping showed least leakage for the greatest convergence. However, if the stopping is expected to offer resistance to convergence or to provide roof support, a dry-wall foam-coated stopping is superior.

For maximum resistance to air leakage, the block or the sheet stoppings (except nylon) should be coated with a sealant. Where strength is not a primary factor and the face of the stopping is coated, the economical cinder block can be used to construct a stopping having adequate resistance to air leakage. Should application of a sealant on block stoppings be impractical, wet-wall construction should be used. The additional expense required in good design and construction of a stopping will ordinarily be repaid many times over by savings in power consumption by the mine fan.