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PERFORMANCE EVALUATION OF SOLID CEMENTITIOUS SEALS

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ABSTRACT

The Bureau of Mines conducted explosion tests on various concrete block bulkheads to evaluate their ability to withstand gas explosion overpressures of 20 psi. The full-scale seals (approximately 6 ft high by 20 ft wide) were constructed in the Bureau’s Lake Lynn Experimental Mine. Of the seven seals tested only the standard type seal, having a 16 in thickness and a center pilaster, maintained its integrity. The same standard type seal without floor keying failed. A standard type seal with no center pilaster but with floor keying failed. All the thin walled seals of 8 in thickness made with mortar between the blocks failed. After being subjected to five gas explosions, each producing a 20- to 22-psi overpressure, the 120-sq-ft standard seal only showed a small hairline crack and had a leakage of 87 ft³/min at a pressure differential of 1 in of water.

INTRODUCTION

Background

Abandoned areas of a mine must be either ventilated or isolated from active workings through the use of explosion-proof seals. To strengthen the strategy for the isolation of abandoned areas in operating coal mines, the Bureau of Mines has conducted explosion and hydrostatic tests on a concrete block bulkhead to evaluate its ability to function as both an explosion-proof bulkhead and a water seal (1,2)5. This masonry bulkhead has withstood explosion and water pressures up to 40 psi, providing a fair degree of explosion isolation for abandoned areas and fire zones.

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5Underlined numbers in parentheses refer to items in the list of references at the end of this report.
According to Bureau research (1) as stated in RI 7581:

"A bulkhead may be considered explosion-proof when its construction is adequate to withstand a static load of 20 psig, provided that the area to be sealed contains sufficient incombustible to abate the explosion hazard in that area and that adequate incombustible is maintained in the adjoining open passage ways."

With adequate incombustible and minimal coal dust accumulations, it is doubtful that overpressures exceeding 20 psig could occur very far from the explosion origin. RI 7581 also states that "...gas-air exchanges between sealed and open areas must be controlled."

Before seals can be erected in an operating mine, they must be incorporated into the mine's ventilation plan which must meet the approval of the local Mine Safety and Health Administration (MSHA) District Manager. Title 30 of the Code of Federal Regulations (CFR) identifies the current requirements for the construction of seals or bulkheads in Part 75.329-2 as follows:

"Pending the development and publication of definitive specifications for explosion-proof seals or bulkheads, such seals or bulkheads may be constructed of solid, substantial, and incombustible materials such as concrete, brick, cinder block, or tile, or the equivalent, sufficient to prevent an explosion which may occur in the atmosphere on one side of the seal or bulkhead from propagating to the atmosphere on the other side; provided, however, that upon publication of definitive specifications, all such seals or bulkheads, including those in place at the time of such publication, shall be required to meet or exceed those specifications."

From this statement one infers the general requirements for seals are that they be constructed of materials that are solid, substantial, and incombustible in a manner sufficient to prevent an explosion on one side from propagating to the other side. MSHA is revising the ventilation code for mines with this concept in mind.

MSHA has identified ten solid block cementitious seal configurations that merit investigation. All of these seals utilize 6-in by 8-in by 15-in solid-concrete blocks. In each of the configurations the seals are keyed to the ribs, using angle iron, and wedged at the roof but without any roof keying. When keying to the floor was done, angle iron was employed. All 1/8-in thick coatings applied utilized a fiberglass-reinforced portland cement. The configurations of special interest are as follows:

(1) Standard type thick-wall seal (wetwall): 16-in-thick seal with mortared joints with a center pilaster of 32-in thickness; keying to the floor;
(2) **Thick-wall seal (wetwall):** 16-in-thick seal with mortared joints with a center pilaster of 32-in thickness; no keying at the floor.

(3) **Thin-wall seal (wetwall):** 8-in-thick seal with mortared joints; center pilaster having a 24-in thickness; keying to the floor; 1/8-in coating on the inby side of the seal.

(4) **Thin-wall seal (wetwall):** 8-in-thick seal with mortared joints; center pilaster having a 24-in thickness; keying to the floor; 1/8-in coating only on the outby side of the seal.

(5) **Thick-wall seal (wetwall):** 16-in-thick seal with mortared joints; keying to the floor; no pilaster.

(6) **Thin-wall seal (drywall):** 8-in-thick seal; drywall construction (no mortared joints); center pilaster having a 24-in thickness; full face coating on both sides of seal; keying to the floor.

(7) **Thick-wall seal (drywall):** 16-in-thick seal; drywall construction (no mortared joints); center pilaster having a 32-in thickness; full face coating on both sides of seal; keying to the floor.

(8) **Thin-wall seal (wetwall):** 8-in-thick seal with mortared joints; center pilaster having a 24-in thickness; no keying to the floor; 1/8-in coating on the outby side of the seal.

(9) **Thick-wall seal (drywall):** 16-in-thick seal; drywall construction (no mortared joints); center pilaster having a 32-in thickness; keying to the floor; 1/8-in coating only on the inby side of the seal; and

(10) **Thick-wall seal (drywall):** 16-in-thick seal; drywall construction (no mortared joints); center pilaster having a 32-in thickness; keying to the floor; 1/8-in coating only on the outby side of the seal.

The Lake Lynn facility has a single entry and a triple entry room and pillar section with twelve crosscuts, which is unique -- no other test facility has a room-and-pillar configuration. This flexible configuration greatly facilitates testing of explosion-proof seals. Most importantly, the LLEM geometry realistically simulates modern mine widths and heights. The facility has been modified to easily accommodate testing of cementitious type seals in two crosscuts between C- and B-Drifts.

**Purpose**

The objective of this research effort is to determine whether these ten solid block cementitious seals can withstand a 20-psi methane-air explosion without losing their structural integrity and resistance to leakage of mine gases.
Full scale explosion-proof seal research provides both input to MSHA for setting adequate standards and useful information to industry for the improvement of mining economics and safety. MSHA is currently reviewing the regulations for explosion-proof seals and needs performance data from full scale dynamic tests for various seals. The Lake Lynn Experimental Mine (LLEM) can easily provide this data, and MSHA has requested U.S. Bureau of Mines assistance in this area.

Acknowledgements

The computer analysis of the pressure pulses acting on the seals was performed by Dr. Glenn Grannemann6 of PRC's Theoretical Support Group. The modification of the crosscuts to accommodate seal installation and the erection of the seals was performed by Mr. John Perry and the Lake Lynn miners under the direction of Mr. George Triebisch, Superintendent of the Lake Lynn Laboratory. Mr. Randolf Lipscomb and Mr. Kenneth Jackson arranged the instrumentation for the tests, conducted the tests, and performed the initial evaluation of the condition of the seals following the explosion. Mr. Brian Murphy from MSHA also assisted in post-test evaluation of the seals. The leak rate tests on the standard seal were conducted by Mr. George Triebisch and Mr. John Perry with the assistance of the Lake Lynn miners.

EXPERIMENTAL PROCEDURE

All of the configurations that were tested were made from solid concrete blocks. All the tests were conducted in the LLEM. Figure 1 shows a map of the LLEM. The seals were erected in the crosscuts between C-Drift and B-Drift and subjected to an approximate 20-psi methane-air explosion. The seals, erected in the crosscuts, typically were 5 to 8 ft from C-Drift. The ability of each of the various seals to withstand an approximate 20-psi methane-air explosion has been determined and compared with that for the standard seal. The standard seal (fig. 2) has a 16-in wetwall with a 32-in pilaster and a cross-sectional area of about 120 ft². It is keyed to the ribs and the floor using angle iron (5 in by 6 in) and wedged at the roof. Along the ribs the angle iron, spaced about 24 in apart, was bolted and grouted into solid rock. On the floor when keying was used, the angle iron was bolted to the floor and a concrete ramp was built with a 6-in elevation. In all the comparison tests, the standard seal was located in the first outby crosscut between C-Drift and B-Drift.

C-Drift of the LLEM is 1700 ft long, 20 ft wide, approximately 7 ft high and closed at the inby end. Mixtures of natural gas and air are prepared at the face (closed end) and confined by a thin plastic

6Deceased
diaphragm. The 47-ft-long gas zone contained about 6,600 ft\(^3\) of near stoichiometric methane-air mixture. The mixture was ignited by an electric match which was placed at the face. The instrumentation in C-Drift included pressure transducers and flame sensors. Signals from the instruments were fed through long cables to the surface where they were recorded on a Microvax II computer. The computer was used to collect the data, process it, and prepare graphs in the desired units. Figure 3 shows a typical pressure versus time trace for the station located 134 ft from the face, which is at the Number 2 (outby) crosscut where the test seal was located. This diagram shows the signature for the pressure acting on the seal between 260 and 1,100 milliseconds. The calculated impulse per area for this event is 3.17 psi-sec.

The seal to be tested was constructed as it would be for MSHA approval as a part of the mine's ventilation plan.

To measure the leakage through the standard seal after it had been subjected to numerus 20-psi explosions, a double brattice technique utilizing a 0.5-ft\(^2\)-window in the measurement brattice was employed (3). A centrifugal fan was used to blow air from B-Drift through the window and through the seal into C-Drift. Air velocity through the window was measured with a vane type anemometer. The differential pressure across the seal and measurement brattice was measured.

**DISCUSSION OF TEST RESULTS**

In the first test series, a standard type seal, having a 16-in wetwall with a 32-in pilaster, was positioned in the first outby crosscut. A wetwall seal similar to the standard type seal except without floor keying was in the second outby crosscut. A wetwall seal of 8-in thickness, having a 24-in pilaster and a coating on the explosion side of the seal, was keyed into the floor in the third outby crosscut. A wetwall seal of 8-in thickness, having a 24-in pilaster and a coating on the side opposite the explosion, was keyed into the floor in the fourth outby crosscut. Of these four seals, only the standard type seal in the first outby crosscut maintained its integrity, clearly indicating the need for adequate keying of the seal to the floor and ribs.

The results are summarized in table 1, which lists a maximum pressure of 21.8 psi acting on the standard seal in the Number 1 crosscut (outby) and a pressure of 15-psi on the 8-in-thick test seal in the Number 4 crosscut (outby).

In the second series of tests, three seals were located in crosscuts between C- and B-Drifts. The seals constructed from solid concrete blocks were all tightly keyed into the ribs, and wedged at the roof. The standard seal withstood the explosion without any apparent damage. A modified seal (no pilaster) was located in the second outby crosscut between C- and B-Drifts. The explosion removed portions of the blocks in the uppermost layer, causing it to lose integrity. In the third
FIGURE 3. - Pressure trace at 134-ft station for seal configuration #7
<table>
<thead>
<tr>
<th>Seal Type Description</th>
<th>Location from face, ft</th>
<th>Maximum overpressure, psi</th>
<th>Impulse per area, psi-sec</th>
<th>Degree of damage</th>
<th>20-psi test outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard seal, thick wall, wetwall, pilaster, floor keying</td>
<td>84</td>
<td>21.8</td>
<td>4.55</td>
<td>None</td>
<td>Passed</td>
</tr>
<tr>
<td>Thick wall, wetwall, pilaster, no floor keying</td>
<td>134</td>
<td>21.2</td>
<td>4.03</td>
<td>Large opening at roof; 2 large cracks at left outby side; bottom displaced about 1 inch</td>
<td>Failed</td>
</tr>
<tr>
<td>Thin wall, wetwall, pilaster, floor keying, coating on inby side</td>
<td>234</td>
<td>19.3</td>
<td>2.98</td>
<td>All blocks removed except for bottom row</td>
<td>Failed</td>
</tr>
<tr>
<td>Thin wall, wetwall, pilaster, floor keying, coating on outby side</td>
<td>304</td>
<td>approx 15 at # 4 seal because of venting through the opening formed when # 3 seal at 234-ft location failed</td>
<td>Large crack at top; blocks missing on outby side; pilaster sheared off</td>
<td>Failed</td>
<td></td>
</tr>
<tr>
<td>Thick wall, wetwall, no pilaster, floor keying</td>
<td>134</td>
<td>17.1</td>
<td>3.74</td>
<td>Minor damage; marginal stopping intact; at least 20-psi half blocks removed at roof line; approximately 1 sq ft leak area formed</td>
<td>Passed</td>
</tr>
</tbody>
</table>
Table 1.- Summary of seal test conditions and results--continued

<table>
<thead>
<tr>
<th>Seal</th>
<th>Type</th>
<th>Location from face, overpressure, ft</th>
<th>Maximum psi</th>
<th>Impulse psi-sec</th>
<th>Degree of damage</th>
<th>20-psi test outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Thin wall, drywall, pilaster, floor keying, coating on both sides</td>
<td>234</td>
<td>17.7</td>
<td>2.45</td>
<td>Destroyed; only a few blocks remained on and near ribs</td>
<td>Failed</td>
</tr>
<tr>
<td>7</td>
<td>Thick wall, drywall, pilaster, floor keying, coating on both sides</td>
<td>134</td>
<td>19.7</td>
<td>3.17</td>
<td>All blocks removed except for a few along both ribs and on the floor</td>
<td>Failed</td>
</tr>
</tbody>
</table>
outby crosscut a thin drywall seal of 8-in thickness with a pilaster of 24-in thickness was positioned. A coating had been applied on both sides. Catastrophic failure of the seal resulted.

The standard type seal, which had been subjected to three 20-psi level methane/air explosions and two weaker explosions, was examined for air leakage. Over the range of 0.1 to 1 in of water pressure, the volumetric rate of leakage was linear with the square root of pressure, as to be expected. At a pressure differential of 0.1 in of water the leakage was 22 ft³/min and at 1 in it was 87 ft³/min. The leakage rate across the seal was not measured before the seal was subjected to the series of explosions.

Not only must the seal be physically strong, but also it must effectively control gas-air exchanges between sealed and open areas. What would constitute a tolerable leakage rate for a seal design for use in an operating mine needs more consideration.

In the third series of tests, a modified seal (drywall) was located in the second outby crosscut between C- and B-Drifts. It was 16 in thick, constructed with a 32-in pilaster, and coated on both sides. No mortar was used between blocks. The explosion removed more than 90 pct of the seal, causing catastrophic failure. The standard seal still located in the outby crosscut between C- and B-Drifts withstood the explosion without any apparent damage.

Seal configurations 8, 9, and 10 mentioned in the introduction did not have to be tested. The results from earlier tests with stronger seals implied that these three would also have failed.

In operating mines, the keying of the seal is achieved by digging into the ribs and the floor before erecting the seal, which promotes strength and control of the gas-air exchanges between sealed and open areas.

CONCLUSIONS

Of the seven seals tested only the standard type seal maintained its integrity. A standard type seal without floor keying failed. A standard type seal with no pilaster but with floor keying failed. All the thin walled seals of 8-in thickness made with mortar between the blocks failed — neither the use of a pilaster nor floor keying provided sufficient strength against the 20-psi explosion. The addition of coatings did not significantly augment the seal strength; however, coatings placed on high strength seals whose physical integrity would not be impaired by a 20-psi explosion would help to minimize the air and gas leakage through the seal.

The leakage through the standard seal after it had been subjected to more than five severe explosions was 22 ft³/min at a pressure differential of 0.1 in of water and 87 ft³/min at a pressure of 1 in of
water. Not only must the seal be physically strong, but also it must effectively control gas-air exchanges between sealed and open areas.

RECOMMENDATIONS

Further tests on seals should be conducted in the LLEM. More specifically, it is suggested that the following be done:

- For the stronger modified seals, the pressure level at which catastrophic failure occurs should be determined;
- Various ways to augment the strength of other solid block seal designs currently used in operating mines should be pursued, such as the use of angle iron to augment keying;
- Novel seal designs such as (1) foams, both reinforced phenolic and cementitious, and (2) light weight masonry blocks should be evaluated; and
- How best to effectively control gas-air exchanges between sealed and open areas needs to be pursued.

REFERENCES

