

Experimental Study of the Effect of LLEM Explosions on Various Seals and Other Structures and Objects¹

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¹ This report details work performed at the request of the Mine Safety and Health Administration and the West Virginia Office of Miners' Health, Safety, and Training in support of their investigations into the Sago mine explosion. This report has not undergone external peer review.

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Executive Summary

The Mine Safety and Health Administration (MSHA) and the West Virginia Office of Miners' Health, Safety, and Training (WVOMHS&T) have been investigating the January 2006 Sago coal mine explosion in West Virginia, which resulted in 12 fatalities. In early Spring 2006 the MSHA and the WVOMHS&T requested the Pittsburgh Research Laboratory (PRL) of the National Institute for Occupational Safety and Health (NIOSH) to evaluate the effects of explosions on specific mine ventilation seals and other structures and objects at the NIOSH Lake Lynn Experimental Mine (LLEM) to help answer questions that arose during their investigations of the Sago coal mine explosion. Six large-scale explosion tests were conducted in the LLEM from April to October 2006. The protocols for these tests, and in particular the procedures for constructing the various Omega block seals, were primarily developed by MSHA and WVOMHS&T. NIOSH developed the experimental procedures at the LLEM that would provide the required range of explosion pressures against the seals. Three 40-inch thick seal designs using Omega 384 low-density block were constructed at the LLEM and exposed to various explosion pressures. These seal designs are identified in the report as the 2001 design, the "hybrid" design, and the "Sago" design.

The 2001 design Omega block seal (80 inches high) located in crosscut 2 survived all six LLEM explosions, with maximum pressures up to 51 psi. The 2001 design Omega block seal (88 inches high) in C-drift was destroyed during Test 2, which had a maximum explosion pressure of 51 psi. The difference in heights between these two seals was a contributing factor to the fact that the crosscut 2 seal survived an explosion at 51 psi and the C-drift seal was destroyed during Test 2 at 51 psi. The higher seal would be weaker for the same seal thickness. The "hybrid" Omega block seal in crosscut 3 survived an explosion at a pressure of 25 psi and failed during another explosion at a maximum pressure of 39 psi at the seal. Based on these LLEM tests, it appears that the hybrid seal design is weaker than the 2001 seal design. The "Sago Omega block seals" were constructed in crosscut 3 and C-drift before Test 3. The crosscut 3 seal survived an explosion pressure of 18 psi and was destroyed during an explosion with a maximum pressure of 35 psi at the seal. The C-drift seal survived an explosion pressure of 21 psi and was destroyed during an explosion with a maximum pressure of 57 psi at the seal.

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Based on these LLEM tests, it appears that the “Sago” seal design is weaker than the 2001 seal design, yet it still complies with the requirements of 30 CFR 75.335(a)(2).

During these LLEM explosion tests, the distance of seal debris travel was also measured. In Test 5, the C-drift seal was destroyed during an explosion with a maximum pressure of 57 psi, and the seal debris was thrown over 500 ft. In Test 6, the C-drift seal was destroyed during an explosion with a maximum pressure of 93 psi, and the Omega block debris was thrown over 900 ft. During these LLEM tests, the explosion pressure effects on other structures and objects were also documented, as described in the text.

The information in this report will be used as supporting data for the MSHA and WVOMHS&T investigation reports of the Sago coal mine explosion.

Summary and Conclusions

Several seal designs using Omega 384 block were constructed at the LLEM during 2006 and exposed to various explosion pressures. All of the seals were constructed of Omega low-density blocks with nominal dimensions of 8-in by 16-in by 24-in. The blocks were alternated to stagger the joints. In the 2001 design, properly mixed BlocBond mortar was applied to all of the block-to-block interfaces and all the block-to-strata interfaces, including the floor. There were some differences between the 2001 design and the “hybrid” and “Sago” designs. The main differences between the “hybrid” design and the 2001 design were that the “hybrid” design was installed on a ¼-in thick layer of dry BlocBond and that the entire first course of block was put into position prior to any mortar being applied to the block. For all subsequent courses with the “hybrid” design, the mortar was applied by gloved hand to the block joints prior to placement of each block. The main differences between the “Sago” design and the 2001 design were that the “Sago” design was installed on a 1½-in thick layer of dry BlocBond and that the mortar was forced into the vertical joints after the blocks were positioned for all courses of blocks. Comprehensive details of the three seal construction procedures are in Appendix B.

A summary of the results of the explosions against the three seal designs is listed in table 13. The first two columns list the type of seal design and the location in a crosscut or in C-drift at the LLEM. The next two columns list the seal height and width. All the seals were nominally 40 in thick. When the coating thickness on the faces of the seal and the mortar thickness are included, the total seal thickness was about 41 in. The next column lists the highest explosion pressure at which a particular seal survived. The final column lists the explosion pressure at which a particular seal was destroyed. This value is the maximum pressure measured during a particular explosion at the middle front of the seal. If a particular design of seal was destroyed during more than one explosion, the lower explosion pressure is listed. For example, a “Sago” seal in C-drift was destroyed at 57 psi during Test 5 and at 93 psi during Test 6, so only the lower pressure of 57 psi is listed in Table 13. The ultimate strength of a particular seal would be somewhere between the values in columns five and six. For example, the 81-in high “hybrid” seal survived an explosion pressure of 25 psi and was destroyed during a later explosion at 39 psi. Therefore, its ultimate strength is greater than 25 psi but less than 39 psi.

Table 13 – Summary of explosion pressures on various seals

Seal Design	Location	Height, in	Width, in	Highest Pressure at which seal survived	Explosion Pressure at which seal was destroyed
2001	X-2	80	226	51	n/a
	C-drift	88	224	n/a	51
“hybrid”	X-3	81	226	25	39
“Sago”	X-3	80	226	18	35

	C-drift	88	224	21	57
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Note: n/a means that no data were available for this scenario.

The 2001 design Omega block seal (see Appendix B1 for construction details) located in X-2 survived all six LLEM explosions, with maximum side-on pressures of 13, 15, 22, 23, and 51 psi. Note that all the explosion pressure values were smoothed data that were averaged over 10 ms. The pressure data here are all from transducers near the geometric center in front the seals. The 2001 design Omega block seal (Appendix B3) in C-drift was destroyed during Test 2, which had a maximum head-on explosion pressure of 51 psi. The difference in heights between these two seals was a contributing factor to the fact that the X-2 seal survived Test 6 at 51 psi and the C-drift seal was destroyed during Test 2 at 51 psi. The C-drift seal was ~88 in high and the X-3 seal was ~80 in high. The higher seal would be weaker for the same seal thickness [Anderson 1984]. The “hybrid” Omega block seal (Appendix B2) in X-3 survived Test 1 at an explosion pressure of 25 psi and failed during Test 2 at an explosion pressure of 39 psi. Based on these LLEM tests, it appears that the hybrid seal design is weaker than the 2001 seal design.

The “Sago Omega block seals” were constructed in X-3 and C-drift before Test 3, as described in Appendixes B4 and B5. The X-3 seal survived Tests 3 and 4 at explosion pressures of 16 and 18 psi, respectively. It was destroyed during Test 5 at an explosion pressure of 35 psi. The C-drift seal survived Tests 3 and 4 at explosion pressures of 17 and 21 psi, respectively. It was destroyed during Test 5 at an explosion pressure of 57 psi. During these three tests, the X-3 seal experienced the side-on explosion pressure and the C-drift seal experienced the head-on explosion pressure. The X-3 and C-drift “Sago Omega block seals” both survived Test 4 at explosion pressures of 18 and 21 psi, respectively. The X-3 and C-drift seals both were destroyed during Test 5 at higher explosion pressures of 35 and 57 psi, respectively. This indicates that the magnitude of the explosion pressure is more important than the direction of the explosion propagation in regard to seal survival or failure. Another “Sago Omega block seal” was constructed in C-drift for Test 6, and it was destroyed at an explosion pressure of 93 psi, as expected. Based on these LLEM tests, it appears that the “Sago” seal design is weaker than the 2001 seal design.

During these LLEM explosion tests, the distance of seal debris travel was also measured. The C-drift seal was exposed to an explosion pressure of 51 psi in Test 2 and the seal debris was thrown over 800 ft. In Test 2, there was no significant obstacle beyond the C-drift seal that would restrict the debris travel. In Tests 5 and 6, there were two wood cribs and a block stopping beyond the C-drift seal. Even though the cribs and stopping were destroyed in both tests, they would absorb blast energy and therefore limit the debris travel distance. In Test 5, the C-drift seal was exposed to an explosion pressure of 57 psi and the seal debris was thrown over 500 ft. In Test 6, the C-drift seal was exposed to an explosion pressure of 93 psi and the Omega block debris was thrown over 900 ft. During these LLEM tests, the explosion pressure effects on other structures and objects were also documented, as described in the text.

The purpose of these LLEM explosion tests in 2006 was to assist the Mine Safety and Health Administration (MSHA) and the West Virginia Office of Miners’ Health, Safety, and Training (WVOMHS&T) in determining the explosion pressures at which

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various 40-in thick Omega block seal designs would fail and studying the explosion effects on various mine items, including the debris fields resulting from the destroyed seals. The information in this report will be used as supporting data for the MSHA and WVOMHS&T investigation reports of the Sago coal mine explosion.