Protective Technologies

TECHNICAL REPORT

BLAST RESISTANT MODULE DEVELOPMENT AND TESTING

PROTECTIVE TECHNOLOGIES, LLC

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1. Blast Resistant Modules

The threat of blast loads from acts of terror, accidental explosions, and combat scenarios is of major concern to both industry and defense personnel. Protection of individuals and valuable equipment requires the development of technology which can provide resistance to these types of extreme loads. The blast resistant module (BRM) is a modular building which can provide office or storage space in an environment which is protected from specific levels of blast loading. While standard BRMs are rated to resist peak reflected pressure loads in the range of 10-20 psi, Protective Structures has developed a product which handles pressure loads in the range of 60-70 psi, providing a resistance which is much greater than the current industry standard. This report provides a detailed examination of the second round of live experimental testing conducted on the BRM model.

2. Development of BRM

This section contains specific construction techniques and materials that are confidential to HWH Protective Structures, LLC., that are made available only after signing the included NDA form.

3. Experimental Setup

The experimental configuration included three BRMs and a standard ISO container which were organized in a ring formation around an enhanced 9,000 lb cylindrical ANFO charge (TNT equivalency of ~8,010 lbs). All of the structures were located at a standoff distance of 150' to provide a direct comparison of the responses as shown in Figure 1. Table 1 shows a comparison of the four structures.

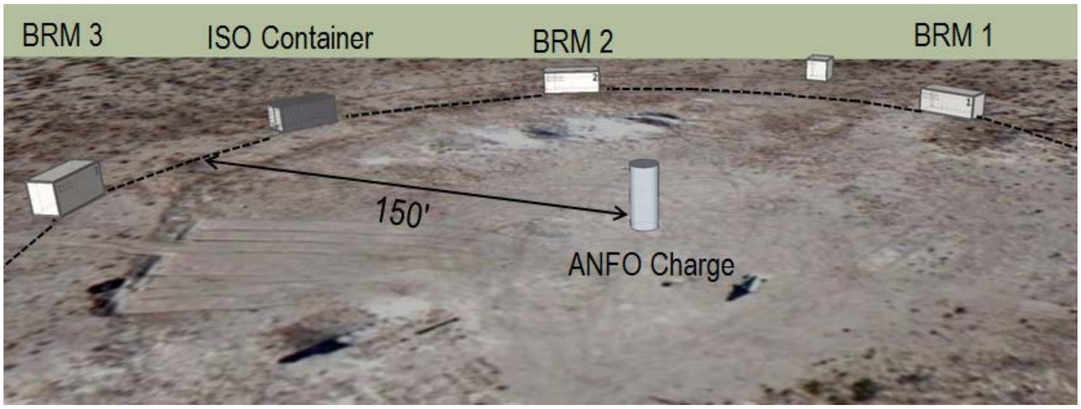

Figure 1: Ring Formation for Blast Testing

The ISO container and all three BRMs were firmly secured to the soil using an embed system shown in Figure 2. The modules were welded at six locations (see image below) to steel plates which attached to an anchor system extending approximately 6 feet into the ground. This arrangement prevented the structures from sliding or tipping over during blast loading and, thus, promoted a true test of the special wall systems which are characteristic of the BRMs.

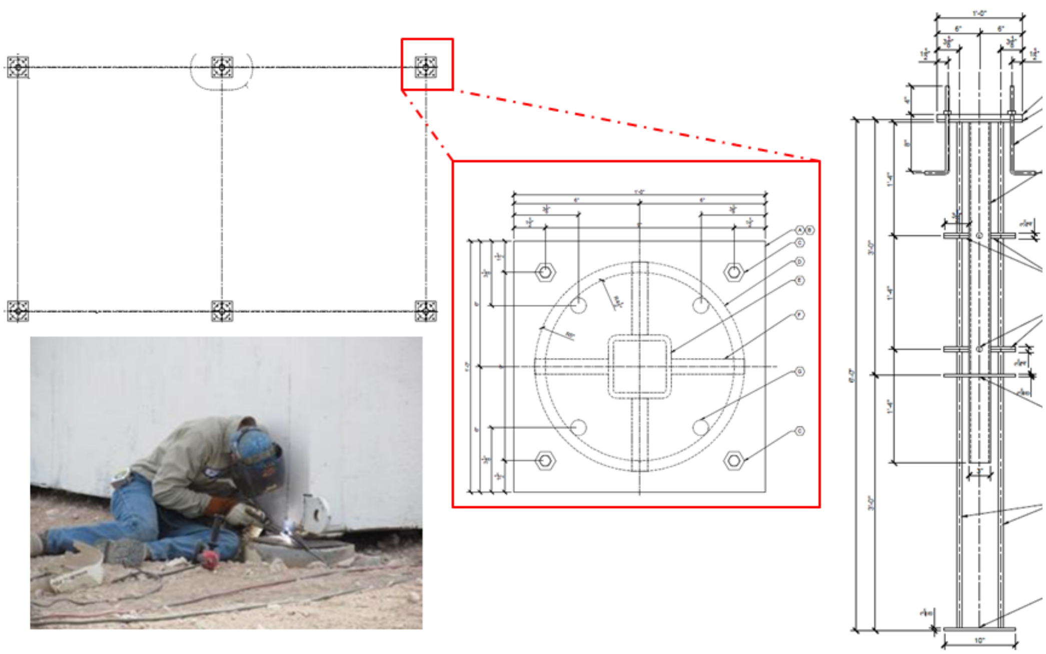

Figure 2: Embed System for Anchoring BRM to Soil (Section View at Right)

Table 1: Comparison of ISO Container and BRM Units

Structure	Loaded Wall Details	Image
ISO Container	Corrugated steel walls	
BRM 1	Hollow	
BRM 2	Hollow	
BRM 3	Sand-filled	

Pressure sensors provided by Applied Research Associates (ARA) were used to collect information regarding the incident and reflected pressures experienced by the structures during testing. Sensors were mounted to the front (directly loaded) walls of the BRMs at mid-height and the one-third locations along the span and at mid-height and mid-span for the side walls as seen in the image above in Table 1. A single sensor was placed inside each structure as well to capture the peak internal pressure. To determine the incident blast wave pressure at the specified standoff distance of 150' as well as two additional distances of 175' and 200', free-standing sensors were placed at these locations along a single radial line extending from the charge. An image of the radial pressure sensor layout is provided in Figure 3.

Figure 3: Radial Incident Pressure Sensors

High-speed video cameras also provided by ARA were placed in three locations to acquire images for a qualitative analysis of the response of the BRMs and ISO container. The first camera captured a broad view of the charge and all of the structures being tested such that the propagation of the shock wave and fireball towards the modules could be examined. An image is provided in Figure 4. The second camera provided a closer view of BRM 3 and the ISO container to show details of projectile impacts and the response of the walls to the reflected pressure. The third camera was placed inside of BRM 3 and monitored the motion of the internal walls and office setup shown in Figure 5.

Figure 4: High-speed Camera View of Blast Event

Figure 5: Office Setup in BRM 3

4. Test Results

The image sequence in Figure 6 shows the progression of the explosive event and response of BRM 3. Frame (a) shows the pre-test state of the structure next to the ISO container. Frame (b) occurs at detonation and displays the flash from the ANFO charge being projected onto the BRM surface. The shock wave and fireball can be seen at the right of frame (c), and frame (d) provides a visual of the projectile impact on the BRM wall which preceded the shock wave. In frame (e), the structure is experiencing the reflected pressure from the shock wave on the front face, followed by the BRM being surrounded by pressure and dust in frame (f).

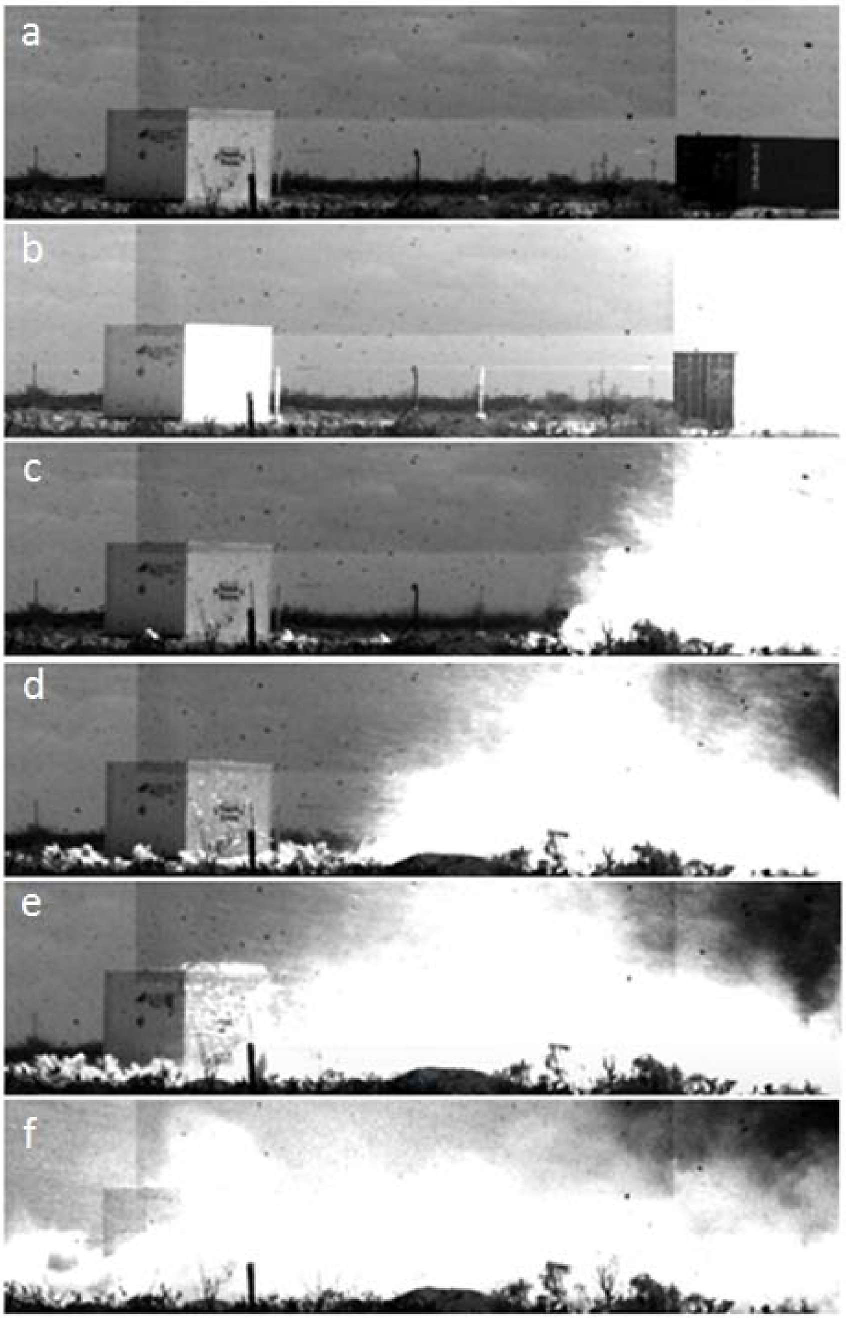

Figure 6: Progression of Blast Event

The pressure-time histories acquired from the free-standing radial sensors and corresponding impulses for the test are shown in Figure 7. Considering the spacing of 25' between each device and difference in arrival times, it can be determined that the shock wave velocity was approximately 1700 ft/s when it reached the BRMs. The pressure value determined at the 150' free field sensor was used as a gage for determining the validity of the incident pressures on the side walls of each BRM. A summary of the radial data results is provided in Table 2.

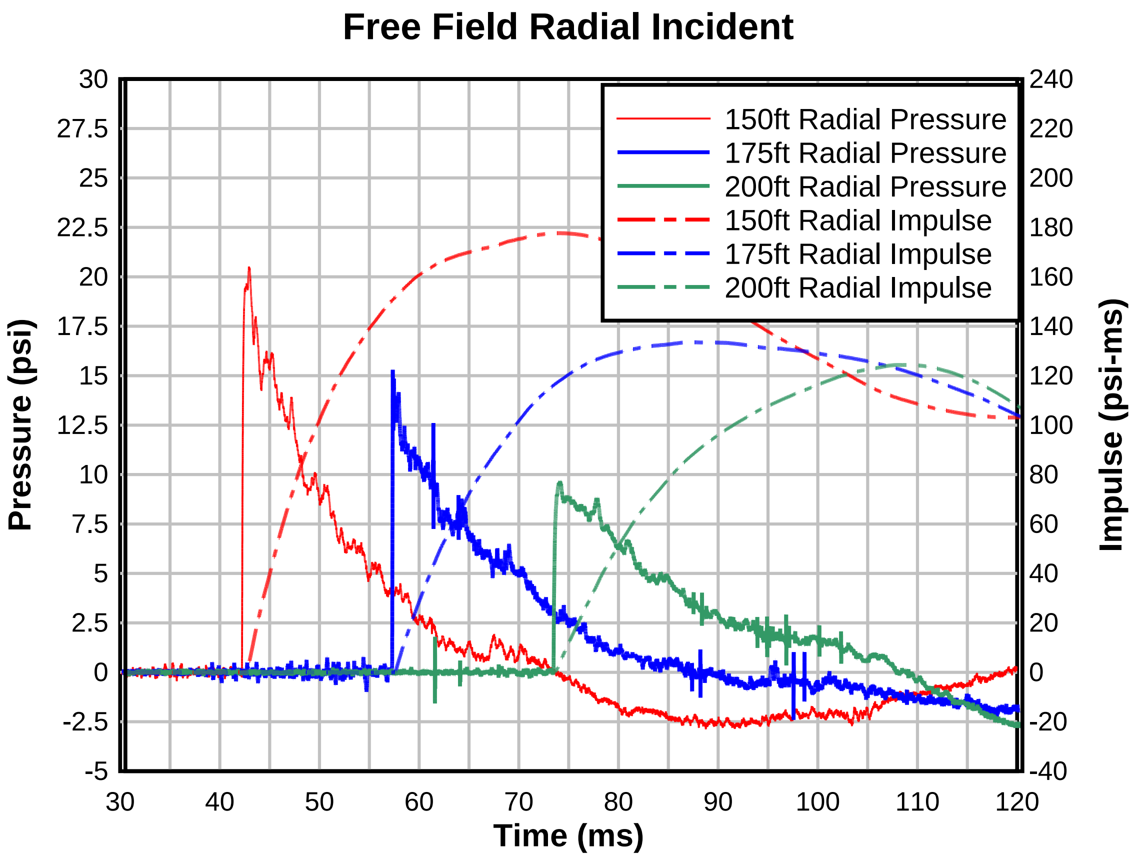

Figure 7: Free Field Radial Pressure-time Histories and Impulses

Table 2: Summary of Data for Free Field Radial Pressure Sensors

Sensor	Peak Pressure (psi)	Duration (ms)	Impulse (psi-ms)
Incident Radial (150')	20.52	31.3	177.6
Incident Radial (175')	15.29	29.6	133.5
Incident Radial (200')	9.67	35.3	124.3

The pressure-time histories acquired by the sensors and corresponding impulses for each BRM are provided in Figures 8-12. The incident pressures were acquired from the sensors located on the sides of the modules, and the reflected pressures were determined from the sensors on the directly loaded wall. Results are shown for sensors which functioned properly during the test.

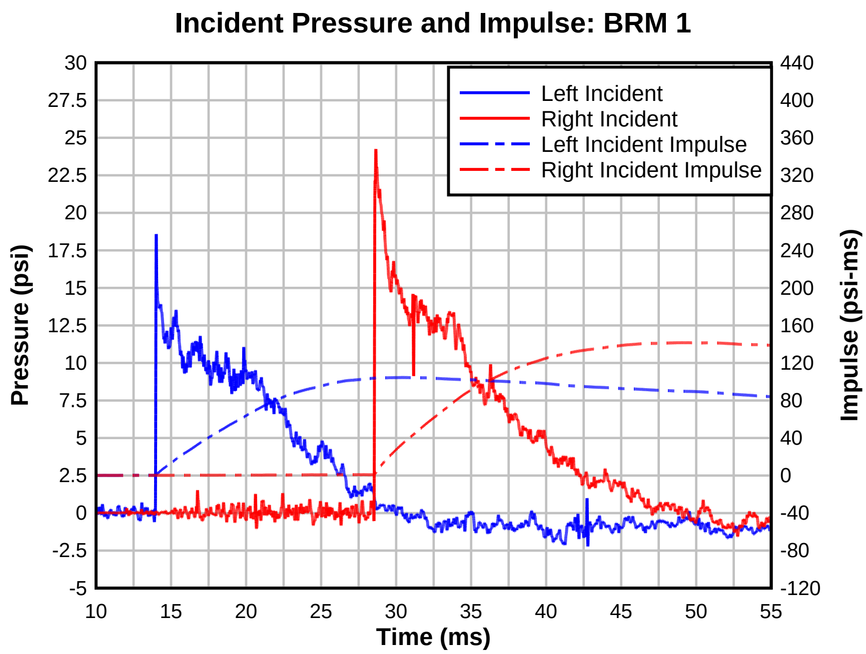

Figure 8: BRM 1 Incident Pressure-time Histories and Impulses

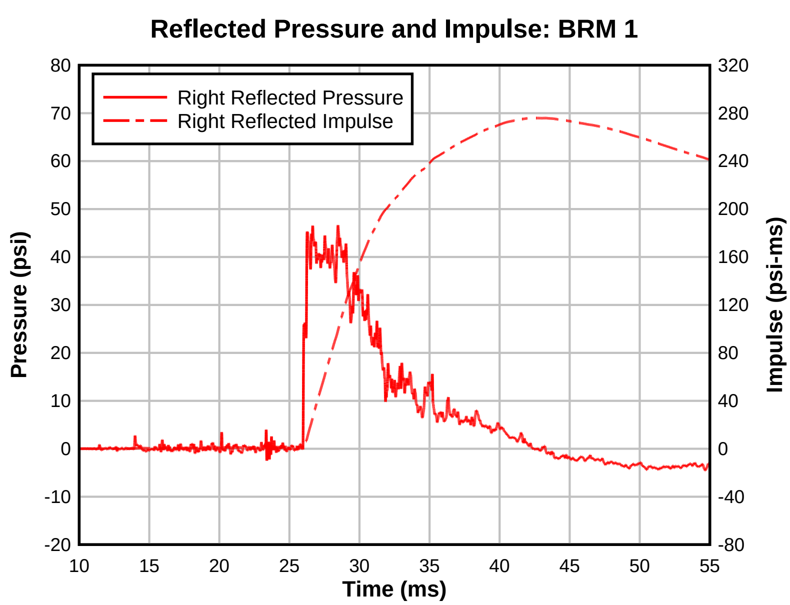

Figure 9: BRM 1 Reflected Pressure-time Histories and Impulses

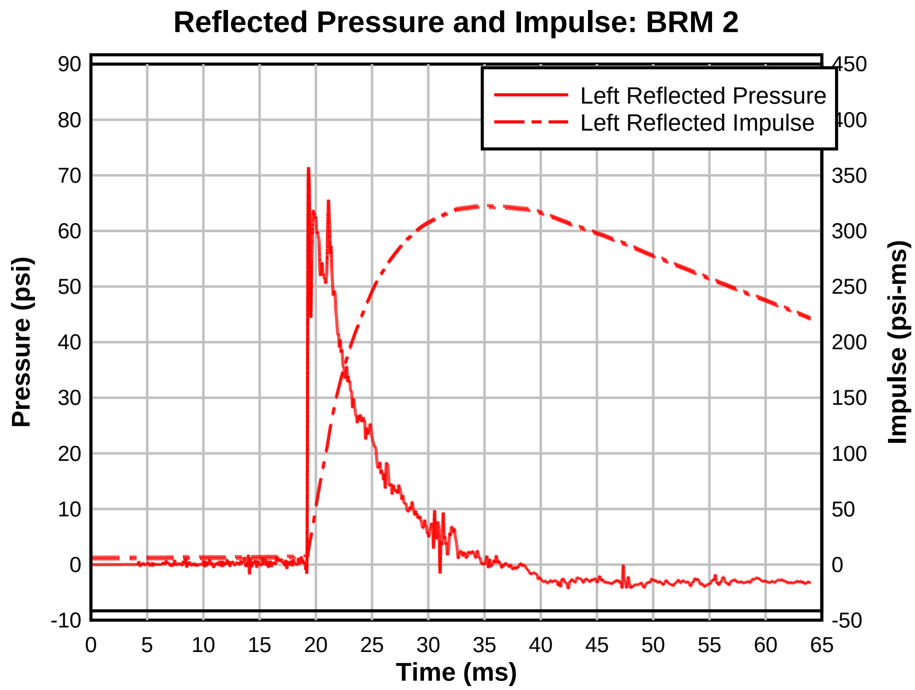

Figure 10: BRM 2 Reflected Pressure-time Histories and Impulses

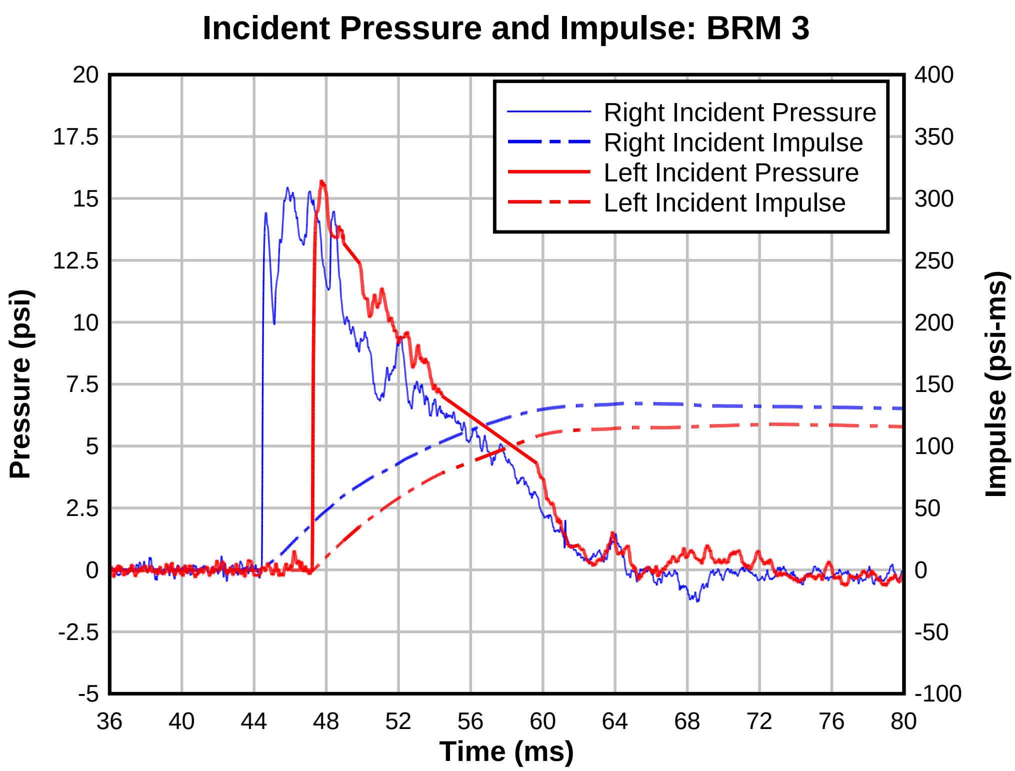

Figure 11: BRM 3 Incident Pressure-time Histories and Impulses

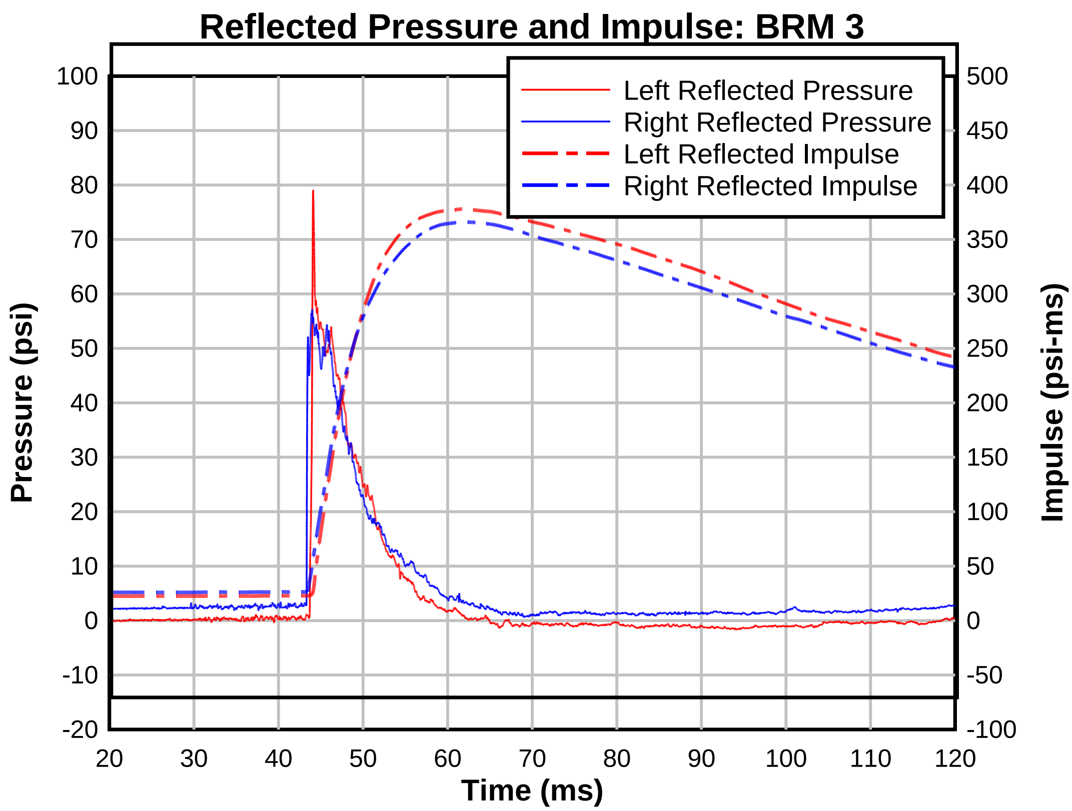

Figure 12: BRM 3 Reflected Pressure-time Histories and Impulses

A summary of the data is provided in Table 3. By averaging the left and right side results for each BRM, an approximate set of peak reflected pressures and impulses can be designated for each module. These values, which provide the expected peak values resisted by the structures, are given in Table 4.

Table 3: Summary of Data for External BRM Pressure Sensors

Sensor	Peak Pressure (psi)	Duration (ms)	Impulse (psi-ms)
BRM 1 Incident Left	18.58	16.5	104.8
BRM 1 Incident Right	24.24	20.5	141.5
BRM 1 Reflected Right	46.62	18.0	275.9
BRM 2 Reflected Left	71.17	15.4	315.2
BRM 3 Incident Left	15.75	25.5	117.6
BRM 3 Incident Right	15.45	19.7	134.4
BRM 3 Reflected Left	78.55	17.9	353.5
BRM 3 Reflected Right	54.54	18.5	338.2

Table 4: Summary of External Peak Pressures and Impulses

Structure	Peak Reflected Pressure (psi)	Duration (ms)	Impulse (psi-ms)
BRM 1	46.62	18.0	275.9
BRM 2	71.17	15.4	315.2
BRM 3	66.55	18.2	345.9

The internal pressure-time history results provide insight into the conditions which would be experienced by a person or piece of equipment inside the structure during blast loading. Figure 13 shows the clear difference in safety level provided by the BRMs and the ISO container. Table 5 provides a summary of the peak internal pressures which were available.

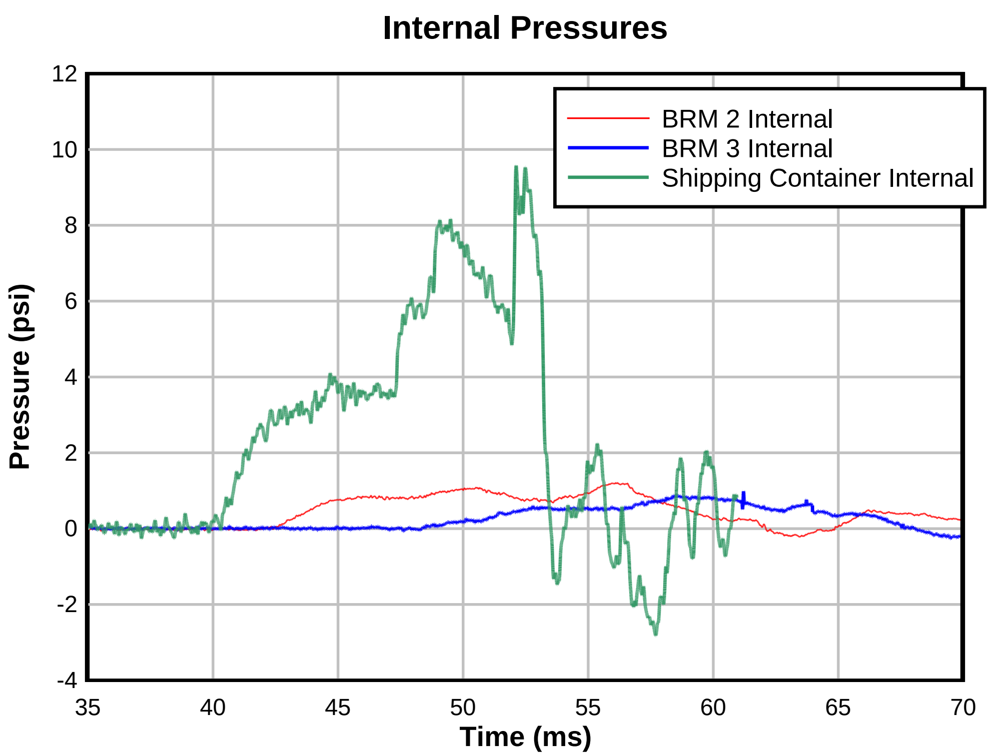

Figure 13: Internal Pressure-time Histories

Table 5: Internal Peak Pressures

Structure	Peak Internal Pressure (psi)
BRM 2	1.20
BRM 3	0.98
ISO Container	9.57*

*prior to gage being disconnected

It was clear from simple observation of the structures after the test that the BRMs performed much better than the ISO container. While the modules showed minimal residual wall displacements, the container was totally demolished as seen in Figure 14. A basic qualitative analysis shows without a doubt that the BRM is clearly a more effective option than the container for resisting the effects of blast loading. The poles seen with each BRM were used to deflect fragments which could potentially damage the pressure sensors during testing. Further details of the response of each BRM are provided below.

Figure 14: BRM 1 (top left), BRM 2 (top right), BRM 3 (bottom left), and ISO Container

The main observable damages for the BRM 3 included paint chipping and small punctures from projectiles on the external faces. No residual deflections were observed in any wall other than that which experienced reflected pressure. It is also worth noting that the mannequin at the desk was still sitting fully upright after the test and was not impacted by any debris or desk items.

For BRM 1 and BRM 2, several of the studs pulled away from the tracks and experienced plastic deformation, causing small localized deflections towards the top and bottom of the section as seen in Figure 14. Minor outer surface punctures of the loaded wall and paint chipping were also observed. As with BRM 3, only the wall which experienced reflected pressure had any residual deflection.

After the completion of the test, all damages for each BRM were deemed repairable. In contrast, the ISO container experienced damage which was well beyond the point of repair and deflections which were immeasurable. The residual deflections for the BRMs, which were readily measurable, are provided in Table 6.

Table 6: Residual Deflections of BRMs

Structure	Maximum Residual Deflection
BRM 1	2"
BRM 2	1¾"
BRM 3	⅜"

5. Conclusions

The results show that the BRM being currently developed provides significantly greater protection to internal contents than the standard ISO container. Effectively resisting peak pressures in the range of 45-70 psi, the BRMs are considerably stronger than the typical blast resistant module which is rated for 10-20 psi. BRM 3 (sand-filled wall) performed at an exceptional level, showing close to zero residual deflection of the loaded wall, a peak internal pressure of less than 1 psi, and only minor outer surface punctures and paint chipping on its exterior surfaces. After a thorough inspection of the modules, the few damages which were observed were determined to be fully repairable. These results indicate not only a high grade of protection for persons or equipment which would be occupying the internal space during a high-level blast event, but also the opportunity to economically repair the BRM to a usable state after such an event. With the basic structure successfully tested, door and window options can be implemented to expand the usability of the BRM.