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BLAST RESISTANT GLASS BLOCK SYSTEM

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1. SUMMARY

With the increased threat and awareness of terrorist and criminal attacks from explosive ballistic devices, responsible government and commercial organizations are responding with more stringent building requirements along with better products and construction methods. In the past, the majority of injuries and deaths to building occupants have been caused by shattered glass fragments sent flying through the air from the blast force. Building on a strong tradition of safety and security in its glass block product line, Pittsburgh Corning Corporation has developed and tested a new generation of patent pending blast resistant products.

Flat glass fenestration has made good progress in blast resistance by utilizing glass lamination and framing techniques to allow a glass pane to flex, so that even when the glass cracks the laminate layer will hold the pane together limiting the scattering of glassfragments. Pittsburgh Corning has enhanced the natural structure of glass block construction to allow the fenestration flex elastically to blast pressures. The structure behaves like a flexible web of independent glass units. Where laminated flat glass will often crack and release fragments during a successful blast test, there was no cracking or loss of glass in tests conducted on Pittsburgh Corning's glass block system.

Engineering analysis supplemented with shock tube testing performed by Baker Engineering and Risk Consults, Inc. (BakerRisk) has determined that the glass block panels of this design with sizes ranging between 4 feet by 4 feet to 8 feet by 8 feet would perform to ASTM "Minimal Hazard" or GSA "Performance Condition 2" or better for:

- GSA Level C and Level D
- UFC Type I threats at 25m and 45m standoff distances, and Type II threats at 10m and 25m standoff distances

Smaller and larger windows are available, but may have a more limited range of blast resistance.

GSA is the General Services Administration that is responsible for all government buildings, and UFC is the Unified Facilities Criteria - DoD Minimum Antiterrorism Standards for Buildings that are military.

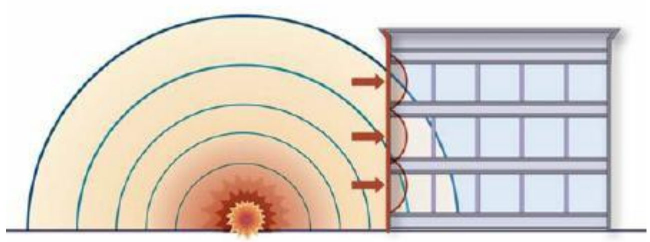
The reports by BakerRisk include:

- Design limits for window sizes and blast characteristics
- A Certified Test Report covering GSA Levels C and D as well as UFC Type I and II threats at conventional building standoff distances
- Successful test results for a blast of longer duration and lower peak pressure to

simulate a petrochemical type of blast as well as multiple blast tests on a single panel
- Installation guideline

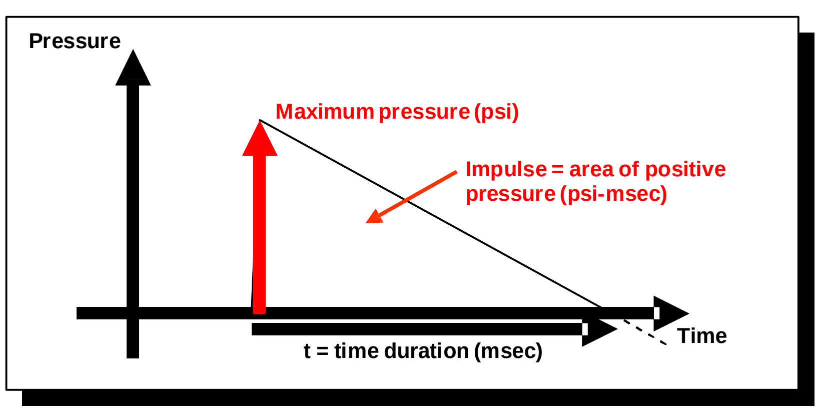
2. BLAST FUNDAMENTALS

An explosion will cause variations in air pressure, called shock waves, to radiate from the source of the blast as illustrated in this diagram from FEMA's Building Design for Homeland Security Unit VI-14.



The actual effect of a blast is a function of its type, magnitude, duration and distance from where the blast took place. Standoff distance is a distance maintained between the building and the potential location of an explosive detonation, like a sidewalk or parking lot. Standoff distances will be longer where there is potential to detonate a larger explosive device, like one driven in a car, and shorter where the device could be carried.

With a nearly infinite range of explosive devices and potential standoff distances, standards have been developed to simplify blast parameters for testing and application purposes. To that end, a blast pulse is often simplified to a triangular shape where the pressure rises from ambient pressure almost instantaneously and then declines linearly back to ambient as diagramed below.



The key parameters used to define a blast in standards and specifications for fenestration are:
- Maximum pressure is the highest level of pressure above ambient that is typically reached immediately after detonation. Measured in psi (pounds per square inch), it is often referred to as peak pressure and applied pressure. Overpressure is often used to describe pressures above ambient.
- Impulse is a function of the pressure and duration and is the area under the pressure curve from detonation to when the pressure returns to ambient. Measured in psi-msec

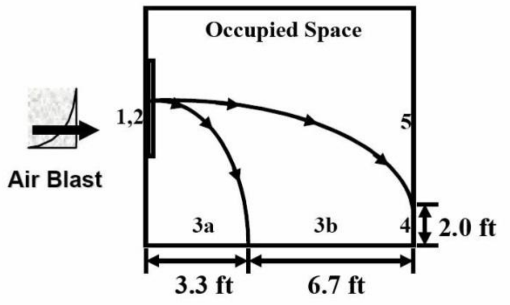
(pounds per square inch - milliseconds) it is often simplified as the area of the triangle in the above diagram.

The other key parameter for fenestration is how well it resists a blast in order to protect people inside of a building. The two commonly used standards defining that protection are the ASTM Hazard Rating and the GSA Performance Condition and are summarized in the following table that was provided by BakerRisk.

Table 1: ASTM Hazard Rating and GSA Performance Condition

ASTM Hazard Rating	ASTM Description	Similar GSA Performance Condition	GSA Description
No Break	The glazing observed not to fracture and there is no visible damage to the glazing system.	1	Glazing does not break. No visible damage to glazing or frame.
No Hazard	The glazing is observed to fracture but is fully retained in the facility test frame or glazing system frame, and the rear surface (the surface opposite the air blast loaded side of the specimen) is intact.	2	Glazing cracks but is retained by the frame. Dusting or very small fragments near still or on floor acceptable.
Minimal Hazard	The glazing is observed to fracture and the total length of tears in the glazing plus the total length of the pullout from the edge of the frame is less than 20% if the glazing sight perimeter. Also there are less that 3 pinhole perforations and no fragment indents anywhere in a vertical witness panel located 3 m (120 in.) from the interior face of the specimen, and there are fragments with a sum total untied dimension of 25 mm (1.0 in.) or less on the floor between 1 m (40 in.) and 3 m (120 in.) from the interior face of the specimen. Glazing dust and slivers are not accounted for in the rating.	3A	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
Very Low Hazard	The Glazing is observed to fracture and is located within 1 m (40 in.) of the original location. Also, there are three or less pinhole perforations and no fragment indents anywhere in a vertical witness panel located 3 m (120 in.) from the interior face of the specimen and there are fragments with a sum total united dimension of 25 mm (1.0 in.) or less on the floor between 1 m (40 in.) and 3 m (120 in.) from the interior face of the specimen. Glazing dust and slivers are not accounted for in the rating.	3B	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
Low Hazard	The glazing observed to fracture, but glazing fragments generally fall between 1 m (40 in.) of the interior face of the specimen and 0.5 m (20 in.) or less above the floor of a vertical witness panel located 3 m (120 in.) from the interior face of the specimen. Also, there are ten or fewer perforations in the area of a vertical witness panel located in 3 m (120 in.) from the interior face of the specimen and higher than 0.5 m (20 in.) and none of the perforations penetrate through the first layer of the witness panel.	4	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 ft. from the window at a height no greater than 2 ft. above the floor.
High Hazard	Glazing is observed to fracture and there are no more than ten perforations in the area of a vertical witness panel located 3 m (120 in.) from the interior face of the specimen and higher than 0.5 m (20 in.) above the floor or there are one or more perforations in the same witness panel area with a fragment penetration into the second layer of the witness panel.	5	Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor.

Both standards are based on a room that is 3 meters deep as illustrated in the following diagram taken from GSA-TS01-2003.



As an example, Pittsburgh Corning's (48-inch by 64-inch) blast resistant glass block panels passed three certification tests by achieving an ASTM "Minimal Hazard" and GSA "Performance Condition 2" when tested with a maximum pressure at or above 11 psi and impulse of 97 psi-msec on each test. Note that there were no cracks in the glass and no loss of material in any of the tests. The ASTM "Minimal Hazard" and GSA "Performance Condition 2" ratings were given due to some material separation between the glass blocks and some deformation in the aluminum framing.

3. STANDARD AND GOVERNMENT AGENCIES

ASTM – ASTM International, previously American Society for Testing and Materials

From their web site:

ASTM International is one of the largest voluntary standards development organizations in the world-a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing and trade in the global economy.

ASTM has developed a document with designation F 1642 – 04 titled "Standard Test Method for Glazing and Glazing Systems Subject to Air blast Loadings." It is used to define standard testing procedures and resulting "Hazard Rating" as those used by BakerRisk.

GSA – General Services Administration

GSA is a government agency that provides support to federal, state and local government agencies and to contractors and suppliers providing goods and services to them. Part of their function is to qualify suppliers and products. For blast resistant fenestration, they provide GSA Test Protocol GSA-TS01-2003 titled "US General Services Agency Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings." Its introduction states:

"This test standard is intended to ensure an adequate measure of standardization and quality assurance in the testing of window systems... This standard is the sole test protocol by which blast resistant windows and related hazard mitigation technology and products shall be evaluated for facilities under the control and responsibility of the US General Services Administration (GSA)."

It is used to define standard testing procedures and resulting "Performance Condition" as those used by BakerRisk. GSA has prescribed the following Building Classifications:

GSA Building Classification	Maximum Pressure	Impulse	Performance
Level A	0	0	NA
Level B	0	0	NA
Level C	4 psi	28 psi-msec	3b or better
Level D	10 psi	89 psi-msec	3b or better
Level E	Classified	Classified	per spec

Pittsburgh Corning's blast resistant glass block panels have been tested at maximum pressures and impulses greater than those prescribed for GSA Level C and GSA Level D and successfully passed with no loss of material and a rating of "Performance Condition 2".

ISC - Interagency Security Committee

The Interagency Security Committee was formed after the 1995 domestic terrorist bombing of the Alfred P. Murrah federal building in Oklahoma City, and reports into the office of Homeland Security. It is responsible for defining the physical requirements for new and existing federal buildings, and utilizes the same criteria that GSA uses.

UFC – Unified Facilities Criteria - DoD Minimum Antiterrorism Standards for Buildings

As described in the Forward to document UFC 4-010-01 dated October 8, 2003 with a change dated January 22, 2007:

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD (AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate.

Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system

In Appendix B, the UFC defines "DoD Minimum Antiterrorism Standards for New and Existing Buildings." Blast levels are classified and referred to as having an "Application Explosive Weight" of I and II where I is greater than II. Table B-1 below taken from UFC 4-010-01 specifies the standoff distances for new and existing buildings.

Table B-1 Standoff Distances for New and Existing Buildings

Location	Building Category	Standoff Distance Requirements			
		Applicable Level of Protection	Conventional Construction Standoff Distance	Minimum Standoff Distance[1]	Applicable Explosive Weight [2]
Controlled Perimeter or Parking and Roadways without a Controlled Perimeter	Billeting and High Occupancy Family Housing	Low	45 m [3] (148 ft.)	25 m [3] (82 ft.)	I
	Primary Gathering Building	Low	45 m [3] [4] (148 ft.)	25 m [3] [4] (82 ft.)	I
	Inhabited Building	Very Low	25 m [3] (82 ft.)	10 m [3] (33 ft.)	I
Parking and Roadways within a Controlled Perimeter	Billeting and High Occupancy Family Housing	Low	25 m [3] (82 ft.)	10 m [3] (33 ft.)	II
	Primary Gathering Building	Low	25 m [3] [4] (82 ft.)	10 m [3] [4] (33 ft.)	II
	Inhabited Building	Very Low	10 m [3] (33 ft.)	10 m [3] (33 ft.)	II
Trash Containers	Billeting and High Occupancy Family Housing	Low	25 m (82 ft.)	10 m (33 ft.)	II
	Primary Gathering Building	Low	25 m (82 ft.)	10 m (33 ft.)	II
	Inhabited Building	Very Low	10 m (33 ft.)	10 m (33 ft.)	II

(1) Even with analysis, standoff distances less than those in this column are not allowed for new buildings, but are allowed for existing buildings if constructed/retrofitted to provide the required level of protection at the reduced standoff distance.
(2) See UFC 4-010-02, for the specific explosive weights (kg/pounds of TNT) associated with designations – I and II. UFC 4-010-02 is For Official Use Only (FOUO)
(3) For existing buildings, see paragraph B-1.1.2.2 for additional options.
(4) For existing family housing, see paragraph B-1.1.2.2.3 for additional options.

UFC 4-010-01 specifies the use of the "ASTM Hazard Rating" as described in Section 2 above. The values of Application Explosive Weights I and II are classified information. For testing, blast maximum pressure and impulse values are determined as a function of the explosive weights the standoff distances listed in the table above.

Based on engineering analysis supplemented with shock tube testing, BakerRisk has determined that the glass block panel would perform to ASTM "Minimal Hazard" for Explosive Weight I at 25m and 45m standoff distances and Explosive Weight II at 10m, 25m and 45m standoff distances.

4. Test Results

Acceptable testing is done with three methods, one using a shock tube, one other with live explosives, and a third using engineering analysis calculations. A live blast test has the advantage of being able to test more than one panel at a time with an actual blast, where the shock tube allows for better control of the blast parameters and can be done more cost effectively. Pittsburgh Corning utilized BakerRisk and their shock tube facility because of their extensive experience and credibility with government agencies. Below is a photograph of BakerRisk's shock tube and a glass block panel bolted in place for testing.

Six 4 feet by 5.33 feet panels were tested at the shock tube facility at BakerRisk. Utilizing sophisticated blast testing, data collection, data analysis and numerical modeling techniques, BakerRisk was able to produce a report delineating the Design Limit and Elastic Limit for panel sizes that would provide the ASTM "Minimal Hazard" or GSA "Performance Condition 2" levels of protection.

For certification purposes, testing included a series of three blasts at a peak pressure of 11.0 psi or higher, and an impulse of 97 psi-msec or higher. It also included a test at 12.6 psi and 94 psi-msec to simulate at Army Corps of Engineers request. A test at 3.6 psi and 93 psi-msec to more closely simulate a chemical blast. In all tests the panels performed at ASTM "Minimal Hazard" or better.

It is also significant to point out that one panel was tested at 6.3 psi and 43 psi-msec, then at 7.6 psi and 52 psi-msec with an ASTM highest rating of "No Break.". That same panel was then tested at 10.9 psi and 107 psi-msec and passed with an ASTM rating of "Minimal Hazard."

It is significant to note that one additional test was done at 3.6 psi and 43 psi-msec to simulate a longer developing petro-chemical blast and to help complete data needed for the analysis. That test also passed with an ASTM rating of "Minimal Hazard."

The test and analysis report from BakerRisk describes results from each shock tube air blast test as well as P-i diagrams derived from their analysis for windows of many sizes, and concluded that windows ranging from 4 feet x 4 feet to 8 feet x 8 feet would meet or exceed ASTM "Minimal Hazard" or GSA "Performance Condition 2" or better for:

- GSA Level C and Level D
- UFC Type I threats at 25m and 45m standoff distances, and Type II threats at 10m and
25m standoff distances

The report also concludes that windows as small as 32 inches x 32 inches and as large as 12 feet x 12 feet would meet or exceed ASTM "Minimal Hazard" or GSA "Performance Condition 2" or better for:

- GSA Level C
- UFC Type I threat at 45m standoff distance and Type II threat at 25m standoff distance

5. SIZES AND INSTALLATION

Pittsburgh Corning's blast resistant glass block system is framed by vinyl and two-piece aluminum channels. The vinyl channel is for protection of the perimeter edges of the glass block. For ease of shipping, installation and for building engineering, it may be preferable to include a structural frame. For testing at BakerRisk, the aluminum channel was bolted to a 3/16" steel frame. Following is a photograph of that structure.

Alternatively, the blast resistant system could be installed utilizing the aluminum two-piece channel. This channel allows for the first piece of the frame to be attached to steel, masonry or concrete substrates, then the glass block panel can be placed into the frame as a unit or assembled in the frame in sections, and finally the second piece of the channel can be snapped into place. Having tested these panels in both orientations allows installation from either the interior or exterior of the building.

Engineering analysis supplemented with shock tube testing performed by BakerRisk has determined that the glass block panel would meet or exceed the ASTM "Minimal Hazard" or GSA "Performance Condition 2" levels of protection for GSA and UFC conditions described for panel sizes between 4 feet by 4 feet and 8 feet by 8 feet. Smaller and larger windows are available, but may have a more limited range of blast resistance.

Quality Glass Block is a provider of high quality Pittsburgh Corning glass block products including blast resistant windows and panels. Structural design and integrity of the building structure including the framework that the blast resistant windows or panels are to be installed in are the responsibility of the building owner and associated design and engineering resources.

Quality Glass Block has a sales and technical support team that is ready to help you design, engineer and specify glass block solutions. Please visit or contact Quality Glass Block through the www.**qualityglassblock.com** web site or call 815-416-1007.

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