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GLASS IS EVERYTHING™

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Laminated Glass for Blast Mitigation

The threat of terrorism is ever-present in our society today. Often explosives are recognized as the weapon of choice by terrorists to make their statements. The increase of incidents since 1993 on civilian targets has heightened concern in our society about a building's safety and the security it offers.

Both active and passive security measures have become more of the standard in today's building designs. Viracon has been asked to assist with recommendations towards the passive design of buildings, more specifically, of the windows. Laminated glass has proven to be an effective solution for blast mitigation.

Laminated glass offers protection when a building is exposed to the threat of explosives. Tests have shown that when windows glazed with laminated glass are subjected to a blast impulse, broken glass fragments tend to adhere to the plastic interlayer rather than spraying building occupants with harmful glass shards or other debris.

Properties of Glazing to Resist Bomb-Blast Attack

The primary cause of glazing damage is the shock or blast wave that expands in all directions from the explosive charge. A secondary cause of damage is debris. The two main sources of debris are the intentional missiles in the composition of the weapon, such as nails, and fragments from the surrounding environment, such as rocks. To resist the damaging effects of a bomb attack, the glazing must be able to withstand these two specific assaults.

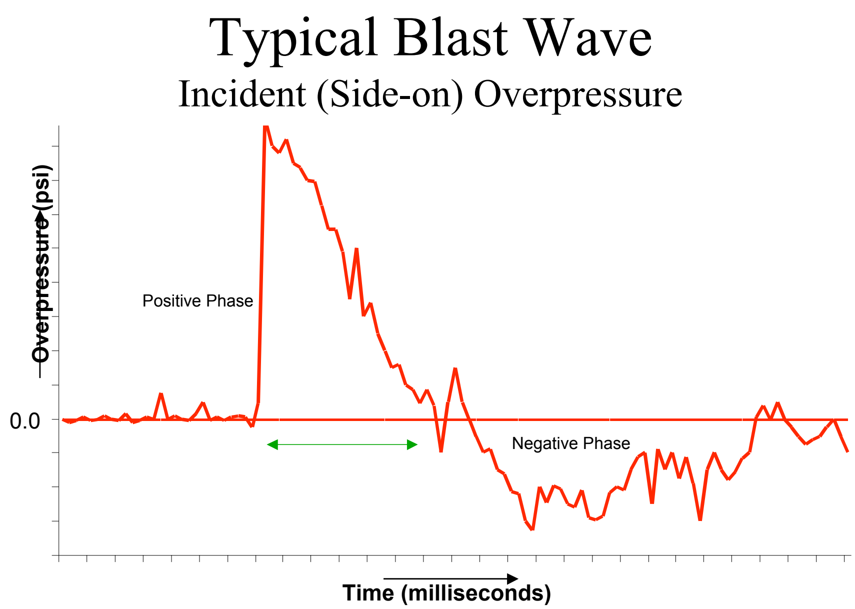
Blast Parameters Affecting Glazing:
- Peak Overpressure - (psi)
- Impulse - (psi-msec)
- Negative Phase

Other Blast considerations:
- Debris
- Glass Retention

Basic Principles of a Bomb Blast

An enormous amount of energy is released when a bomb is detonated. After the detonation occurs, the ambient pressure increases almost instantaneously and promptly begins to decay, forming a nearly triangular overpressure pulse. The peak pressure is called the peak positive overpressure. It represents the pressure seen at a point in space when the shock wave is unimpeded in its motion. The duration of the positive overpressure is called the positive phase duration.

The peak overpressure and positive phase duration determine the specific impulse of the blast wave. Both blast wave parameters influence the property damage and injury that the blast wave can cause. Both parameters need to be specified as some materials can resist rapid high level blast, but will fail as the duration is extended.



Specifying Blast-Resistant Glazing:
The necessary information for designing glazing for bomb-blast mitigation is:

- Peak Overpressure - psi
- Impulse – psi*msec
- Duration - msec

OR

- TNT load equivalent
- Standoff distance
- Site altitude
- Height of Glazing above Blast

In addition to the information stated above, the window size must also be known before Viracon can offer guidance on glazing recommendations.

Bomb-Blast Performance of Glazing:

The two primary aspects of glazing, which characterize blast performance, are:
1. Level of blast load causing the glazing to initially crack or break; and
2. The retention of glass in the frame (Thus, performance of the frame and glazing together is critical.)

If glass leaves the frame it has the potential to become a secondary hazard of the explosion. The hazard is dependent upon the size, shape and velocity of the fragments or shards and where the glass is propelled. Classification guidelines for the performance of glazing during a blast event are used and defined in the diagram below and in Table 1:

Injury Hazard Classification

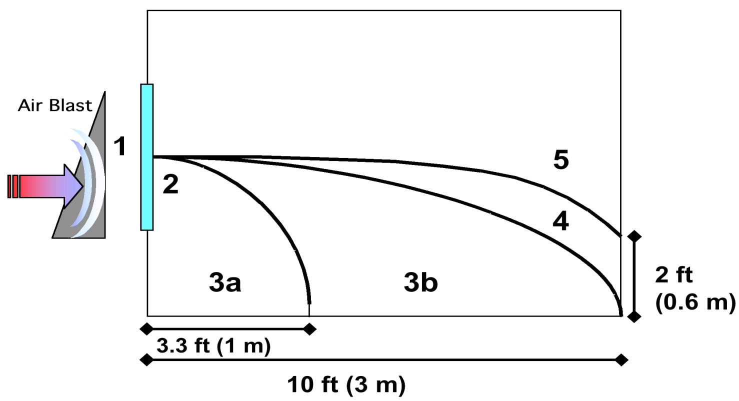


Table 1: Glazing Protection Levels Based on Fragment Impact Locations

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 feet from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 feet from the window.
4	Medium	Medium	Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 feet from the window at a height no greater than 2 feet above the floor.
5	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 feet from the window at a height greater than 2 feet above the floor.

Glazing Performance

Test results conducted by Solutia are summarized below. The size of the glass ranged from 44 _" x 62 _" to 48 _" x 66 _". The glazing was framed into a commercial window system utilizing an approximate 1" glazing pocket. The units indicated as "silicone glazed" were dry glazed on the exterior and wet glazed on the interior with _" deep and _" wide Dow Corning 995 silicone bead. All other windows were dry glazed.

Unit number	Description	Glass Configuration	Performance Level
Test #1: 4.5 psi; ~28 psi*msec			
1	Double Hung Wood Window – No protection	3-mm AN	5
2	Double Hung Wood Window – Retrofit anchored into Concrete	3-mm AN [1.52-mm PVB] 3-mm AN**	3B
3	Retrofit anchored into concrete	6-mm HS [2.54-mm Saflex HP PVB] 6-mm HS	1
4	Commercial Window – Silicone Glazed	5-mm HS [2.29-mm PVB] 5-mm HS	1
Test #2: 4.5 psi; ~28 psi*msec			
1	Commercial Window – Silicone Glazed	3-mm AN [1.52-mm PVB] 3-mm AN**	3B
2	Glazing Alone – Saflex HP	6-mm HS [2.54-mm Saflex HP] 6-mm HS	1
3	Glazing Alone – Saflex HP	3-mm AN [1.27-mm Saflex HP] 3-mm AN**	3B
4	Commercial Window – Silicone/Gasket	5-mm HS [1.52-mm PVB] 5-mm HS	2
Test #3: 21 psi; ~90 psi*msec			
1	Commercial Window – Silicone Glazed	6-mm FT [1.52-mm PVB] 6-mm FT	3B
2	Commercial Window – Silicone Glazed	3-mm AN <12.7-mm Air Space> 3-mm AN** [1.52-mm PVB] 3-mm AN	5
3	Commercial Window – Silicone Glazed	3-mm AN [1.52-mm PVB] 3-mm AN {12.7-mm Air Space} 3-mm AN [1.52-mm PVB] 3-mm AN	3B
4	Commercial Window– Silicone Glazed	5-mm HS [2.29-mm PVB] 5-mm HS	3B

**Viracon recommends when designing with 3mm (1/8") glass plies that the glass be heat strengthened in lieu of annealed.

Metric/Imperial conversion:

3mm =	1/8"	1.27mm =	0.050"
5mm =	3/16"	1.52mm =	0.060"
6mm =	1/4"	2.29mm =	0.090"
12.7mm =	1/2"	2.54mm =	0.100"

System Performance

Equally important to the design of the glass is the design of the frames and attachments to the structure. To realize the greatest protection, the laminate must be retained within the framing members to enable the PVB membrane to behave as a blast shield and prevent debris from entering the occupied space. This can be accomplished with a sufficiently large bite or a structural silicone adhesive.

Blast Consultants

The involvement of blast consultants is standard when projects require windows designed to mitigate the potentially lethal effects of flying glass following an explosive event. Window design is required to balance the features of the glazing, framing, and attachments with the capacity of the supporting structural walls.

Typically all glazing hazard reduction products require product specific test results and rational analyses performed by qualified independent professionals demonstrating the performance of said product under the specified blast loads stating that they meet or exceed the minimum required protection levels.

For design recommendations on laminated glass products for your application, feel free to contact Viracon's Technical Services Department at 800-533-2080.