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**DIVISION OF SPECIALIZED OPERATIONAL SUPPORT  
PHYSICAL SECURITY UNIT****PSU Information Bulletin****BLAST PROTECTION FOR WINDOWS****SUMMARY**

Casualties from explosives are most frequently caused by the fragmentation of structural and other material. Studies on large bombing attacks show that 80% of victims were killed or injured by primary and secondary fragmentation caused by the explosion. In turn, flying glass fragments were responsible for 80% of injuries and deaths caused by fragmentation.

Therefore, in areas where threats from explosives exist, window systems, particularly the glazing, must be carefully analysed to understand risks to occupants. Additionally, Security Risk Management Measures to avoid glass breakage and reduce fragment projection should be implemented to minimize injuries and deaths.

This PSU Information Bulletin will provide an overview on blast protection for windows glazing, covering the following topics:

- Standards on blast protection for windows
- Types of windows and type of glass
- Analysis of the windows glazing
- Mitigation measures
- Shatter Resistant Film (SRF) and windows catcher systems
- Case studies on windows protection

**Please note that any assessment of window system response to a blast depends on several variables. Contact the PSU ([psu@un.org](mailto:psu@un.org)) for assistance with these assessments to ensure an effective evaluation.**

## 1. INTRODUCTION

Casualties from explosives are most frequently caused by the fragmentation of structural and other material. Studies on large bombing attacks indicate that **80% of the victims** were killed or injured by primary and secondary fragmentation<sup>1</sup>, such as:

- Penetrating trauma from the bomb casing fragments;
- Materials implanted within the bomb (e.g., nails, screws, steel balls);
- Local materials made airborne by proximity to the explosion (e.g. debris, stones);
- Flying glass shards.

Of these types of fragments, flying glass was responsible for 80% of injuries and deaths. This can mostly be attributed to glass being weaker than other building components, such as walls, columns, beams, and slabs, which makes them fragment at a lower pressure. Additionally, glass has become one of most used building element in modern urban architecture.

The large percentage of casualties from glass can also be attributed to how it reacts as a result of an explosion. Glass shards under blast overpressure can be projected and hit targets with a velocity and kinetic energy similar to sharp blades that can penetrate various hard and soft surfaces, as shown in Figure 1.

To understand the extent of these penetrative effects, glazing must be carefully analysed during physical security assessments in areas with risks from explosives. Once these effects are identified, Security Risk Management (SRM) measures to avoid glass breakage and reduce shard projection should be implemented in order to meet minimum performance standards and minimize casualties.

**Figure 1: Glass shards penetration of surfaces after an explosion.**



Source: PSU files.

<sup>1</sup> LEAO, D. Counter-IED Operations. Sao Paulo: Icone, 2016.

## 2. STANDARDS ON BLAST PROTECTION FOR WINDOWS GLAZING

Windows glazing protection is regulated by international standards. These standards create patterns and tests to evaluate minimum requirements for protection and to ensure quality of products installed in buildings. It is important to follow internationally recognized standards, that are acceptable by civil engineering associations or government building regulations.

The most usual standards related to blast protection on windows glazing are:

- **GSA-TS01-2003** (General Services Administration / Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings, 2003).
- **ISO 16933:2007** (International Organization for Standardization / Glass in Building – Explosion-resistant security glazing - Test and classification for arena air-blast loading, 2007).
- **PDC-TR 10-02** (US Army Corps of Engineers, Protective Design Center / Blast Resistant Design Methodology for Window Systems Designed Statically and Dynamically, 2012).
- **ASTM F1642-17** (American Society for Testing and Materials / Standard Test Method For Glazing And Glazing Systems Subject To Airblast Loadings, 2017).
- **ASTM F2912-17** (American Society for Testing and Materials / Standard Specification For Glazing And Glazing Systems Subject To Airblast Loadings, 2017).
- **ASTM F2248-19** (American Society for Testing and Materials / Standard Practice For Specifying An Equivalent 3-Second Duration Design Loading For Blast Resistant Glazing Fabricated With Laminated Glass, 2019).

These standards have their own methodology for glass testing and a response classification system to identify what will happen with the glass panel in response to a blast loading. Table 1 presents a comparison of these standards. Although they use different names, the glass response is similar.

**TIP:** **blast resistant** standards (e.g. ASTM F1642, ISO 19633, etc.) are not the same as **ballistic resistant** standards (e.g. UL 752, EN 1063, etc.). These standards are different classifications and apply different tests and parameters.

The **windows glazing response** or **performance condition** is a calculated expectation about what will happen to a window in an explosion. The impact of a blast wave in a window glazing can provoke the total destruction and projection of shards through the room; or can only crack the glass; or the window can resist to impact and do not break.

These windows responses (or performance conditions) is related to the type and size of window, type of glass, use of Shatter Resistant Film (SRF); and the contextual variables, such as the amount of explosive and standoff. Therefore, the same windows glazing system can perform well when exposed to a low amount of explosives but have poor performance when exposed to a higher blast load or when the blast occurs at a closer detonation point.

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**Table 1: Equivalent windows glazing response using different standards.**

UFC 4-010-01	GSA-TS01	ASTM F1642	ISO 16933	UN Acceptability
<b>Below AT Standards</b>	<b>5</b>	<b>6 High hazard</b>	<b>F High</b>	<b>Unacceptable</b>
<b>Very Low</b>	<b>4</b>	<b>5 Low hazard</b>	<b>E Low</b>	
	<b>3b</b>			
<b>Low</b>	<b>3a</b>	<b>4 Very low hazard</b>	<b>D Very low</b>	<b>Acceptable if unlikely blast incidents</b>
<b>Medium</b>	<b>2</b>	<b>3 Minimal hazard</b>	<b>C Minimum</b>	<b>Acceptable</b>
		<b>2 No hazard</b>	<b>B No hazard</b>	
<b>High</b>	<b>1</b>	<b>1 No break</b>	<b>A No break</b>	

According to the “UNSMS Guidelines on Blast Protection for UN Premises” (2020), the acceptable Level of Protection (LoP) for UN premises for blast protection should be at least MEDIUM, using UFC 4-010-01. Equivalent ratings for other international standards include: level 2 (by GSA TS01); level 3 MINIMUM HAZARD (by ASTM F1642); or level C MINIMUM (by ISO 19633). The same Guidelines also consider as acceptable the LoP LOW if the UN premises is located in an area with likelihood of the blast-related event description in the SRM is considered Unlikely or Very Unlikely. Therefore, the windows glazing response can be acceptable at response levels 3a / 3 VERY LOW HAZARD / D VERY LOW in this same condition.

**Annex 1** presents a summary of the standards GSA-TS01-2003 and ASTM F1642, in order to understand the meaning of the performance condition classification in these standards. ISO 16933 classification is similar to ASTM F1642.

The **Case Studies** section provides some examples of windows glazing response depending on the variations in the type of glass, standoff and other parameters.

### 3. TYPES OF WINDOW GLAZING

The fenestrations which are commonly used in typical constructions are<sup>2</sup>:

- Punched windows.
- Ribbon Windows.
- Storefronts.
- Curtain Walls.
- Louvered Windows.

**Punched windows** are individual windows that appear to have been “punched” through the otherwise continuous wall system around it. The façade material is on all four sides of the window. Punched windows are one the most common window systems currently being used in construction. The opening is typically framed with jamb elements, which support the vertical edge of the window. The wall space above and below usually does not provide any lateral support for the window, and it is typically assumed that all of the load is transferred to the vertical jambs.

**Ribbon windows** are essentially a string of windows placed edge to edge forming a horizontal band. They can be installed with or without exposed mullions and appear to form a “ribbon” around the exterior of the building. Ribbon windows are generally connected to the head and sill. Loads are typically transferred through the head and sill members directly to the columns or by cantilever action of sill and head stem walls.

**Storefronts** are a non-residential system of doors and windows mullied, or combined, as a composite structure consisting of larger expanses of glazing. They are typically designed for high use/abuse and strength. The storefront system is non-load bearing and is typically installed between the floor and header or is set back from the exterior wall and provided with a ceiling and sidewalls to close the space between the storefront and wall. The ceilings and sidewalls in some cases provide lateral support to the storefront system and may also need to be designed for blast. For the purposes of storefronts and curtain walls, primary mullions are those that span between points of structural support and are typically vertical. Intermediate mullions are those which frame between the primary mullions and are typically horizontal. There are many different variations of storefront designs, which mean the vertical mullions are not always the primary mullions.

**Curtain walls** are external non-load bearing walls which are intended to separate the exterior and interior environments. Curtain walls can use a variety of materials ranging from precast concrete to glass. Typically, curtain walls span multiple floors and are considered part of the building envelope. Just as for storefronts, primary mullions are those that span between points of structural support and are typically vertical. Intermediate mullions are those which frame between the primary mullions and are typically horizontal. There are many different variations of curtain walls, so the vertical mullions are not always the primary mullions.

**Louvered (or louvred) windows** is a window blind or shutter with horizontal slats that are angled to admit light and air, but to keep out rain and direct sunshine. The angle of the slats may be adjustable,

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<sup>2</sup> U.S. ARMY CORPS OF ENGINEERS. PDC-TR 10-02 Blast Resistant Design Methodology for Window Systems Designed Statically And Dynamically. Omaha, Nebraska: U.S. Army Corps of Engineers Protective Design Center, 19 Apr 2012.

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usually in blinds and windows, or fixed. This type of windows are used where natural air ventilation is required (e.g. living rooms, kitchen, reception area, etc.).

**Figure 2: Types of window glazing**



Source: PDC-TR 10-02.

**The best type of windows for blast protection**

Almost all type of windows glazing can be blast protected. Obviously, **less glazing means a reduced threat of projectiles in case of an explosion**. To protect building occupants from fragmentation, it is important to understand the entire window system, including the glass, frame and substrate. Evaluating windows as a system will ensure robust protection against blast events. The following sections describe window system components.

Louvered windows are not recommended for any Shatter Resistant Film (SRF) application as it would increase the risk of the glass pane to get detached from the revolving frame when loaded and acting as hazardous debris.

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## 4. TYPES OF GLASS

Identifying the type of glass found in a building is important to understanding how it will fragment as a result of a blast event. Not all glass is the same.

The four most common types of glass used in buildings are<sup>3</sup>:

- Annealed glass
- Heat strengthened glass
- Tempered glass
- Laminated glass

**Figure 3: Types of glass**



**Source:** <<https://www.saflex.com/saflex-guide/general/strengths-types-strength-glass>>.

**Annealed glass** is a basic product formed from the annealing stage of the float process. The molten glass is allowed to cool slowly in a controlled way until it reaches room temperature, relieving any internal stresses in the glass. Without this controlled slow cooling, glass would crack with relatively little change in temperature or slight mechanical shock. Annealed glass is used as a base product to form more advanced glass types.

**Heat strengthened glass** is semi tempered glass. The heat strengthening process involves heating annealed glass back up to about 650 to 700 degrees Celsius and then cooling it quickly, although not as fast as with temperate glass. The heat strengthening process increases the mechanical and thermal strength of annealed glass, making it twice as tough as annealed glass. When it breaks the fragments are similar in size to annealed glass, but with a greater likelihood of staying together.

<sup>3</sup> U.S. ARMY CORPS OF ENGINEERS. PDC-TR 10-02 Blast Resistant Design Methodology for Window Systems Designed Statically And Dynamically. Omaha, Nebraska: U.S. Army Corps of Engineers Protective Design Center, 19 Apr 2012.



**Tempered glass** (also called toughened glass) is the most common type of glass used in balustrades or similar structural applications. It is an annealed glass that is heated to about 700 degrees Celsius by conduction, convection and radiation. The cooling process is accelerated by a uniform and simultaneous blast of air on both surfaces. The different cooling rates between the surface and the inside of the glass produces different physical properties, resulting in compressive stresses in the surface balanced by tensile stresses in the body of the glass. The counteracting stresses or surface compression gives toughened glass its increased mechanical resistance to breakage, and when it does break, causes it to produce small, regular, typically square fragments rather than long, dangerous shards that are far more likely to lead to injuries.

**TIP:** Tempered glass is **four to five** times stronger and safer than annealed or untreated glass.

**Laminated glass** is a glass panel built with two or more sheets of glass (annealed, heat strengthened or tempered), laminated together with a Polyvinyl Butyral (PVB) interlayers. A variety of other interlayers than PVB are available which apply a range of other technologies to the application, such as SentryGuard Plus® or SGP interlayer. The laminated glass offers many advantages, mainly in safety and security, so rather than shattering on impact, laminated glass is held together by the interlayer. This reduces the safety hazard associated with shattered glass fragments, as well as, to some degree, the security risks associated with easy penetration. If a glass panel breaks or shatters it is highly unlikely that both laminated panels will break at the same time, which means that the remaining panel and interlayer will support the broken glass and keep it in place as edge protection until it is replaced or secured suitably.

**TIP:** Laminated glass is the most expensive type of glass, but it is the **best option for blast protection.**

### **Polycarbonates panels**

Polycarbonates (PC) have been used in engineering applications, replacing in some cases, the glass in windows. There has been an increased use of polycarbonate in recent years because it is light and more resistant to breaking than glass. When installed, it easily makes a watertight seal. It also diffuses sunlight, which leads to few hot spots. Polycarbonates (PC) are a group of thermoplastic polymers containing carbonate groups in their chemical structures. They are strong, tough materials, and some grades are optically transparent.

Polycarbonate panels can be used as an alternative for blast protection; however, there are some disadvantages to be considered:

- Less visual clarity than glass and less aesthetic for architectonic finishing.
- Toxicity: Bisphenol A (primary component of polycarbonate) may have unpredicted effects on humans, repeated use of them may be potentially hazardous to the health.
- High price. It is much more expensive than glass and other plastics.
- Polycarbonates are not very resistant to scratching, marring and abrasive surfaces; as well they are highly sensitive to abrasive cleaners, alkaline cleaning products and solvents, such as acetone, benzene or any other such organic solvents.
- Polycarbonate material exhibits aromatic sensitivity or is prone to absorb odours.
- The manufacturing process for polycarbonates is not very environmentally friendly, requires very high processing temperatures and is also very expensive. Also, it requires phosgene, which is known for its ill effects on human health and chlorine, which is also environmentally unfriendly.

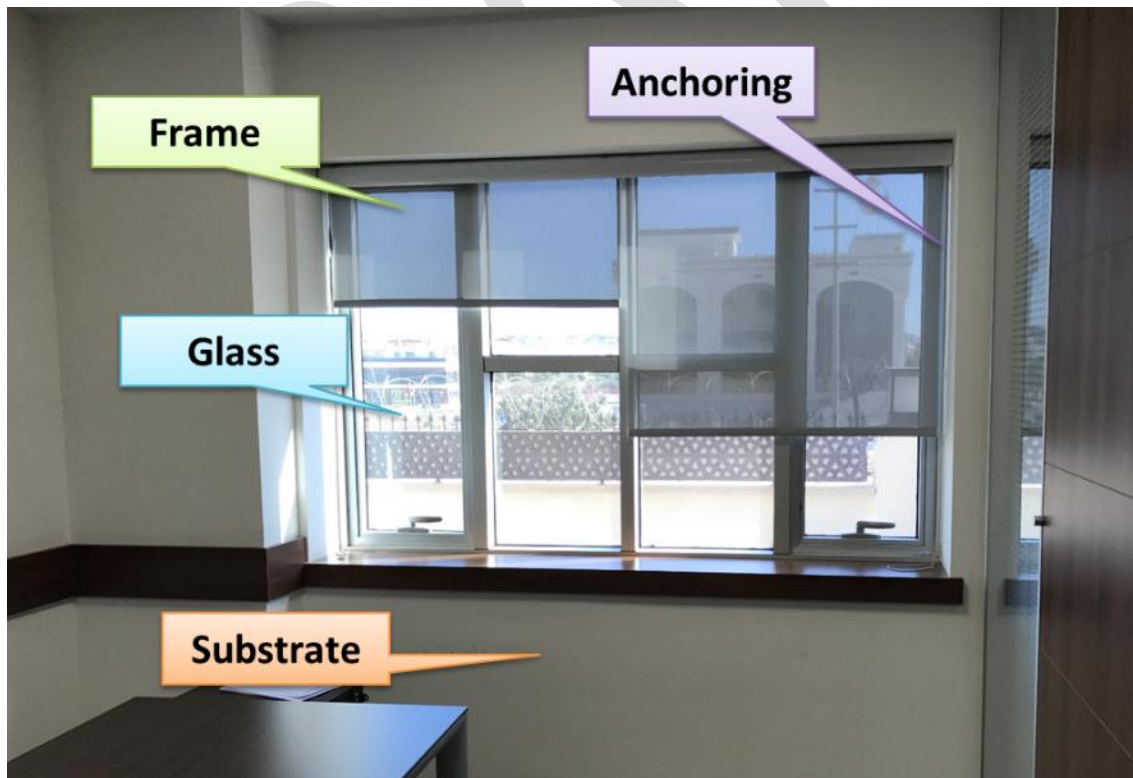
## 5. ANALYSIS OF THE WINDOW GLAZING

Assessing the explosives effect on windows, must include analysis of the entire window structure, as well as the conditions of the explosion (distance, load sized, etc.). Window glazing system components are (see Figure 4)<sup>4</sup>:

- **Glass:** the hard panel, brittle substance, typically transparent or translucent.
- **Frame:** the rigid structure that surrounds or encloses the window.
- **Anchoring:** the support configuration, type, and number of fixing anchors of the windows frame in the substrate.
- **Substrate:** the material which provides the surface on which the window is deposited or anchored, such as the wall, columns, or other structural element.

The physical security principle of “balanced protection” applies to windows system analyses. All components must be proportionally strong to absorb a blast load. For instance, installing a strong glass, such as laminated glass with 30 mm thickness into a weak frame; or in a weak masonry wall will diminish the overall effectiveness of the intended blast resistance because the inferior structural components will easily break in an explosion.

**Figure 4: Window glazing system components**



Source: PSU files.

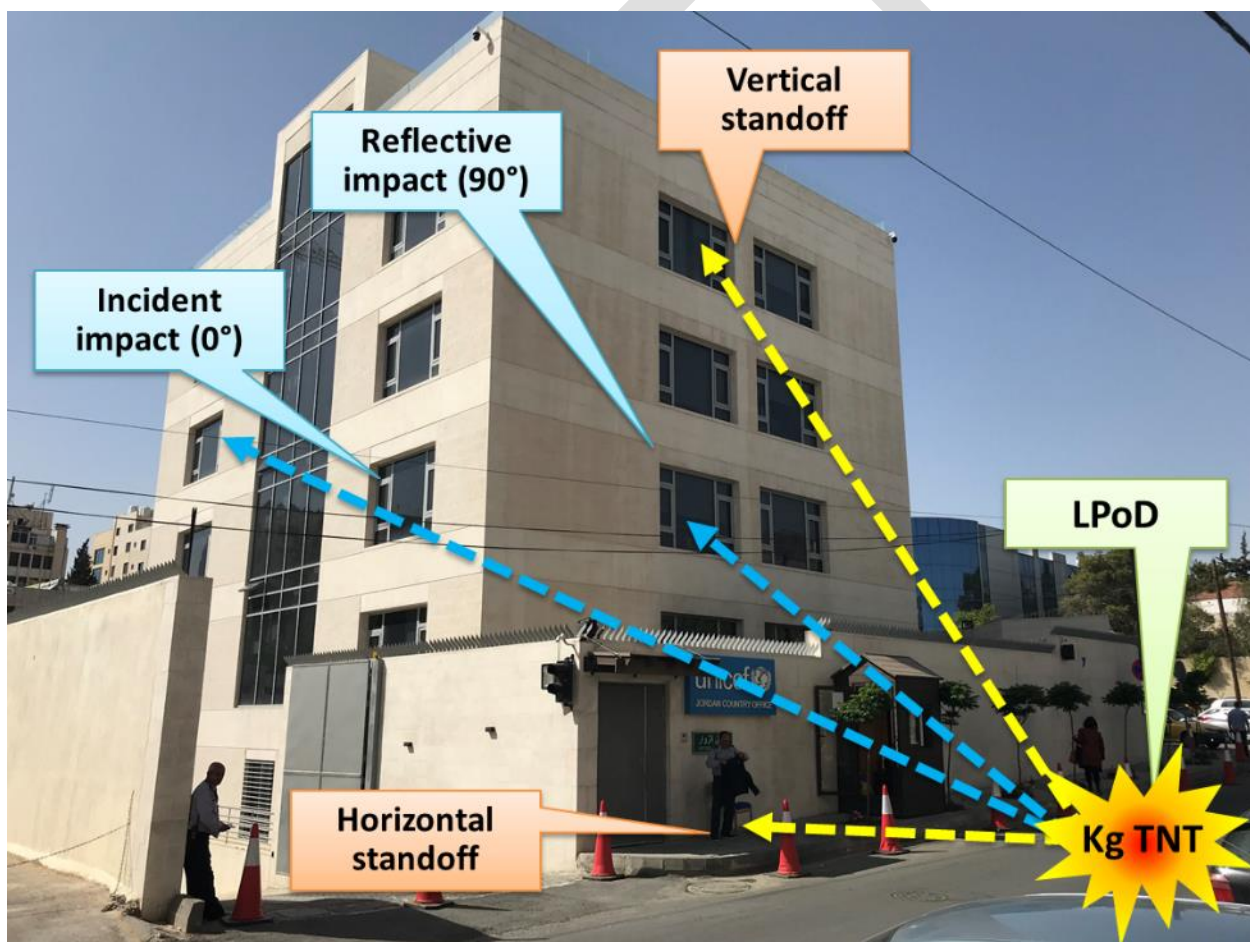
<sup>4</sup> JACQUES, E. and SAATCIOGLU, M. Computer software for the design of blast resistant window retention anchors. Ottawa: University of Ottawa, Canada, 2018.

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Additionally, it is necessary to analyse the blast conditions under which the window system will be submitted. The same window will respond differently depending on the conditions of the blast scenario. In particular, the following variables will change window glazing response to an explosion(see Figure 5):

- **Blast threat size:** the amount of explosive that will be detonated. An estimation based on the Specific Threat Events (STE) of the SRM, in Kg of TNT.
- **Likely Point of Detonation (LPoD):** the positioning of explosive charge related to the window. This will need to be determined through a Red Team exercise<sup>5</sup> or Blast Expert advice.
- **Angle of impact:** the blast wave impact orientation on the windows. It can be a direct impact in the windows, called reflective (considered 90° angle) or passing laterally on the window, called incident (considered 0° angle).
- **Standoff:** the distance (horizontal and vertical) from the explosive charge to the windows.

**Figure 5: Variables in windows glazing analysis**



Source: PSU files

<sup>5</sup> The PSU can perform a red-team exercise for any UN premises that includes the type of explosive and LPoD. Requests should be sent to [psu@un.org](mailto:psu@un.org).

The analysis requires data collection and mathematic calculations. The formulas for windows glazing response are presented in several books about blast protection; and standards, such as the PDC-TR 10-02 BLAST RESISTANT DESIGN METHODOLOGY FOR WINDOW SYSTEMS DESIGNED STATICALLY AND DYNAMICALLY (U.S. Army Corps of Engineers, 2012). See other sources of this information in the REFERENCES section.

The complexity of the blast calculation formulas requires special software. PSU uses the following tools:

- **WINGARD PE** (WINDOW Glazing Analysis Response and Design), provides an accurate analytical model of window response to the effects of an explosion. Developed by ARA Company.
- **BRADS** (Blast-Resistant Window Anchor Design Software), that is a Windows-based tool for the analysis and design of anchoring systems used in blast-resistant window glazing. Developed by Dr. Eric Jacques, structural engineer and researcher from the Virginia Polytechnic Institute and State University.
- **SBEDS-W**. Excel-based tool for design and analysis of windows and mullions subjected to dynamic loads that models' components as equivalent single-degree-of freedom (SDOF) systems. Developed by U.S. Army Corps of Engineers Protective Design Center (PDC).

PSU can support interested UNSMS professionals in windows glazing analysis; the following data about the windows and the expected threat is the information required to do the analysis:

<b>Expected threat/charge</b>	Kg of TNT or type of threat (VBIED, IED, PBIED, etc)
<b>Standoff from the LPoD</b>	Horizontal (m), Vertical (m)
<b>Glass dimensions</b>	Height (mm), Width (mm), Height above floor (mm), Bite (mm)
<b>Angle of incidence</b>	Reflective (0°), Incident (90°)
<b>Panel configuration</b>	Single pane, Double pane
<b>Glass type</b>	Annealed, Heat strengthened, Thermally tempered, Polycarbonate, Other
<b>Layup type</b>	Monolithic, Laminated, SRF Daylight film, SRF Attached film, Other
<b>SRF installed</b>	Yes or no, details of the SRF.
<b>Frame</b>	Aluminium, Steel or other metals, Wood, Other
<b>Substrate type</b>	Reinforced Concrete, Masonry, Steel, Wood, Other
<b>Anchoring</b>	Size and quantity of anchors
<b>Support configuration</b>	Top and bottom, All sides

## 6. SECURITY RISK MANAGEMENT MEASURES for WINDOW PROTECTION



The cartoon above is an ongoing joke between blast experts and architects. If asked about windows protection, blast experts will recommend avoiding the use of glass, or maybe remove all glass from the premises. On other hand, architects love glass. They will argue aesthetics, natural lighting, modernity, and will recommend using glass everywhere. Obviously, there is a balance between these two extreme points of view. Finding the balance is the key.

The SRM measures for blast protection on windows systems should be a combination of:

- Standoff
- Strengthening of the window systems

**Standoff** is the increase and hardening of the distance between the Likely Point of Detonation (LPoD) and the windows glazing. The further the positioning of the explosive device, the less an impact on window. Hardening of standoff involves principles of perimeter protection and access control, that are topics covered in other PSU Information Bulletins.

Options for increasing standoff are presented in the UNSMS Guidelines of Blast Protection for UN Premises (2020):

- Expansion of the perimeter area
- Closure of streets around the premises to avoid uncontrolled pedestrian and/or vehicles
- Use of landscaping, bollards, jersey barriers or planters to establish a hardened perimeter boundary
- Positioning of uncontrolled parking areas as far as possible from occupied buildings
- Positioning of critical utilities, fuel and hazard material storage and waste areas as far as possible away from occupied buildings
- Positioning of occupants in the less vulnerable areas of the building, thereby creating internal and/or vertical standoff

**Strengthening of the windows** are measures taken to improve a window's blast resistance. The window response must be calculated (as discussed above) and, if possible, the windows should be retrofitted to absorb the expected explosive charges to reach an acceptable level of protection. Or, in case of new buildings, the windows must be constructed and installed as blast resistant, following recommended standards.

Strengthening involves implementation of windows systems (glass, frame, anchoring, and substrate) capable to withstand the expected blast threat. There is no "one size fits all" solution, because of the construction and blast variables of each building. The recommendation is to analyse and to calculate the windows response in each situation. Sometimes, the existing window system is satisfactory, and no improvement is required. In some cases, it is necessary to change the whole window system, or, in the worst case, to remove the window altogether and definitively close the opening with another hard element.

Depending on the conditions of the windows system and analysis of the variables, strengthening of the windows can be obtained with installation of safety films, called Shatter Resistant Films (SRF) and window catcher devices, which are detailed below.

### **Recommended features of blast resistant windows**

The UFC 4-010-01 Minimum Antiterrorism Standards for Buildings (US DoD, 2018) is one of the most used references to blast protection, accepted worldwide. This standard provides the following recommendations for blast resistant window glazing:

- **Laminated glazing:** it is the best option for blast protection. While more expensive initially, is less expensive over its life cycle.
- **Glazing and thickness:** for glazing in exterior building elements such as storefronts, doors, windows, curtain walls, clerestories, and skylights provide no less than **6 mm** (1/4 inches) nominal **polycarbonate** or **laminated glass** for exterior windows or skylights. When using insulating glass units (IGU), use the polycarbonate or laminated glass for the innermost pane as a minimum.
- **Glazing frame bite:** requirements for structurally or non-structurally glazed windows or skylights should be in accordance with ASTM F 2248. For laminated glass provide a glazing frame bite in accordance with ASTM F 2248. For polycarbonate provide a glazing frame bite of no less than 1.5 times the polycarbonate thickness. Monolithic glass or monolithic acrylic used as a single pane or as the inner pane of a multi-pane system is not allowed for the purposes of complying with this standard. Apply structural silicone bead or glazing tape to both sides of the glass panel for single pane glazing but only to the inboard side for insulating glass units.
- **SRF and windows catchers:** According to UFC 04-010, the use of window retrofits incorporating alternative window treatments such as Shatter Resistant Films (SRF) and blast curtains **are not acceptable** alternatives for new buildings or existing buildings subject to that standard. The primary reason for that is the fact that such solutions commonly have much shorter design lives than laminated glazing, which requires their replacement multiple times as compared to laminated glazing. In the case of blast curtains, operational procedures must be in place to ensure that they always remain closed for them to be effective.

## Frame members

For static design of aluminium and steel frames, it is recommended to follow standard ASTM F 2248. Frames made of other materials are acceptable, but their performance must be established with dynamic analysis or testing. The deflections limit for frame members designed statically is 1/60 of the length of the glazing supported edge, regardless of anchor spacing, when subjected to a load of two times the glazing resistance determined from ASTM E 1300-09a. The member should be checked based on section properties determined from the design strength calculations under loading of two times the glazing resistance at yield strength of the frame material.

- For **punched** and **ribbon** windows, the length of the supported edge is the longest span of a single pane of glass, regardless of any intermediate support connections.
- For **storefront** and **curtain wall** systems, the glazing supported edge length used in the deflection calculation is dependent on whether the frame member under consideration a “primary” or “intermediate” mullion is. A “primary” mullion is a frame member which spans between points of structural support, e.g., floor to floor while an “intermediate” mullion is one which spans between primary mullions. The length of the glazing supported edge for primary mullions will be taken as the full span between points of structural support. The length of the glazing supported edge for intermediate mullions will be taken as the longest edge of a lite of glass, which is supported by that mullion. The deflections of both mullions are restricted to 1/60 of the supported edge length when subjected to two times the glazing resistance applied over the tributary area of the glazing for the frame member in question.

Details on frame calculations and windows analysis are presented on **PDC-TR 10-02 Blast Resistant Design Methodology for Window Systems Designed Statically and Dynamically** (US Department of Defense, U.S. Army Corps of Engineers Protective Design Center, 2012).

## Limitations of blast resistant windows

Unfortunately, there are limitations on blast protection for windows glazing. Depending on the windows glazing characteristics and the blast variables, some windows systems are impossible to be retrofitted. Scientific research and tests demonstrate that glass with less than 6 mm thickness (1/4 in.) and annealed glass, in general, do not offer blast protection, even with installation of SRF and windows catchers.

These types of glass and thickness cannot withstand blast loads and the security film (SRF) will be useless and only create a **false sense of security**. Similar conditions happen in shorter standoffs, weak frames and weak substrates.

Figure 6 illustrates an example of windows system that cannot possibly be strengthened. Those windows in the picture are fixed in a hollow masonry block wall, light wood frame, annealed glass 4 mm thickness. The windows are positioned 5 meters from the LPoD and the expected threat is 50 kg of TNT (NEQ). All calculations and simulations demonstrate that there is no way to protect those windows. The feasible and safe solution is the close off the windows openings with a wall; or to close the room for people, using it only for storage.

One possible solution in this case is the installation of secondary glazing units (Figure 7). That is an additional windows system (including glass and frame) over the existent windows, creating a sacrificial

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layer. This option is recommended to buildings where is not possible to change the windows system (e.g. historical buildings) or the room occupation cannot be used to non-person activities. In this case, it is necessary to analyse the wall (substrate) and structural building conditions to receive the secondary layer.

**Figure 6: Limitations on blast protection for windows glazing.**



Source: PSU files.

**Figure 7: Secure secondary windows glazing.**



Source: <<https://www.sheerwaterglass.co.uk/blog/secondary-glazing-consumer-guide/>>.

See the Case Studies section other examples of windows glazing response depending of type of windows system.

**TIP:** whatever the performance condition of the window, consider avoiding the positioning of persons close to windows glazing. When set upping an office or other room inside the premises, prefer to put desks and chairs close to walls and not in line up with eventual glass projection line.



## 7. SHATTER RESISTANT FILM (SRF)

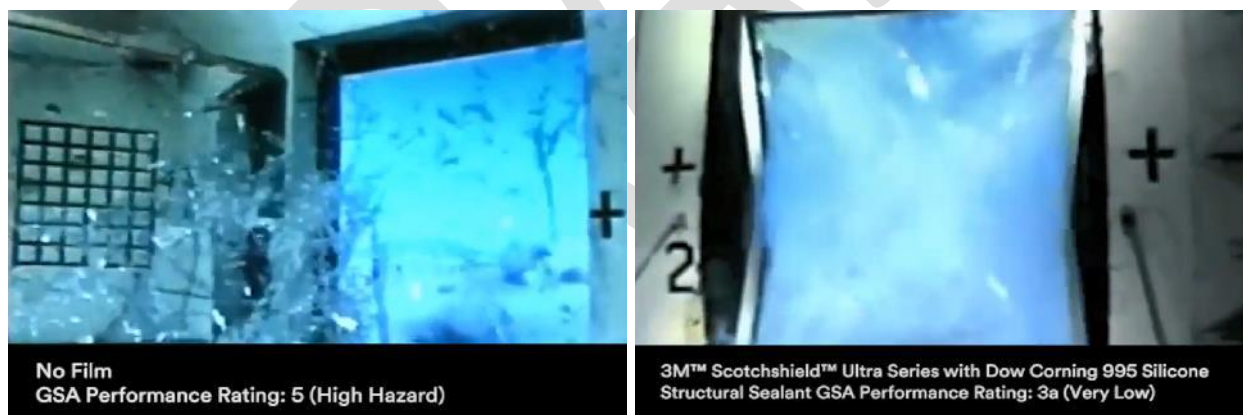
Shatter Resistant Film (SRF) is a polyester laminate film that is applied on the inside face of a pane of glass to mitigate the effects of shattering glass inside a building as a result of an external blast or impact<sup>6</sup>.

When properly installed, SRF forms an almost invisible protective coating (membrane) on the interior side of the glass surface. The film is attached to the glass with extremely aggressive pressure sensitive adhesive. This adhesive is applied to the film at time of manufacture and is protected by a release liner until installed. When stress causes the glass to break, the film can stretch and withstand some or all of the energy generated by the stress. The result is that the broken glass may remain within the framing system preventing shards of glass becoming lethal projectiles (Figure 8).

Other names for SRF:

- Anti-Shatter Film (ASF)
- Anti-Fragmentation Film (AFF)
- Fragment Retention Film (FRF)
- Blast Protective Film (BPF)

**Figure 8: Windows glazing response without and with SRF**



Source: <<https://www.youtube.com/watch?v=jgJMT7viZss>>.

SRF can be also used in windows to mitigate deliberate threats, such as:

- Accidental impacts.
- Breaks from burglary or illegal intrusion.
- Windstorms.
- Spontaneous glass breakage due environmental conditions.
- Solar and heating control.

<sup>6</sup> 3M Center. Windows Films for Safety and Security Applications Course. Minneapolis: 3M Corporate Headquarters, 2016.

The security films are tested and certified by international standards, such the previous mentioned standards for blast response. Additionally, they are also tested in specific standard to evaluate the physical properties, such as:

- **ASTM D882** (Standard Test Method for Tensile Properties of Thin Plastic Sheeting), used to test tensile and break strength and other physical properties.
- **ASTM E903-12** (Standard Test Method For Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres), used to test solar performance properties.
- **ANSI Z97.1-2015** (Safety Glazing Materials Used in Buildings - Safety Performance Specifications and Methods of Test), used to test impact resistance.

### SRF characteristics

There are two types of SRF manufacturing methods:

- **Conventional construction:** single or double layer polyester film, with a thick pressure sensitive adhesive on one side of the film and a scratch-resistant hard coat on the other. The performance will be better as the thickness increases. The usual thickness varies from 7 to 14 mils.
- **Micro-layered construction:** uses tens of layers of material in the same thickness as one layer of a conventional film. Micro-layered films alternate between a stiff layer and a gummy layer, to obtain added performance. These alternating layers add strength to the window and add tear resistance to the film.

SRF are also classified and identified based on the follow properties:

- **Physical properties of SRF:** film colour; tensile strength; break strength; tear resistance; thickness; puncture propagation tear.
- **Solar performance properties:** visible light transmission; visible reflection; ultraviolet transmission; solar heat gain coefficient.
- **Performance testing:** impact resistance for safety glazing; windstorm protection; blast protection.

All these properties can be used in a technical specification for selection and purchasing. However, the most important property that needs to be analysed is the performance testing. Using Figure 9 as an example of a technical data sheet from an SRF manufacturer, it is possible to see many physical properties and solar performance properties. However, **the “Film thickness 8 mils” or “Tensile strength 32,000 PSI”, does not offer information about the effectiveness of the film under a blast load.**

When analysing the performance testing, it is possible to ascertain if the film will meet the required blast protection by verifying the standard used (GSA and ASTM F1642); the type of glass tested (annealed 6 mm, tempered 6 mm, etc.); the installation method; the blast load (expressed in overpressure and impulse); and finally, the windows response in these conditions.

**TIP:** the measurement unit used for SRF thickness is the mil. Mil is one-thousandth of an inch (0.0254 mm); and equals 25.4 microns (micrometres). The thicker the film, less flexible is it. The usual film thickness varies from 4 mils (0.1 mm) to 15 mils (0.38 mm). There is no minimum thickness required by the UN. Although 8 mils (0.2 mm) are the most film used in UN buildings, modern films can absorb similar blast impacts with less thickness.

In this example, the information about the blast load tested (e.g. 9 psi, 60 psi-ms) can be converted as scaled distance  $Z=16.2$ . With the scaled distance, blast experts can calculate and create many scenarios of standoff and explosive charge to analyse if the window protection is sufficient .

**Figure 9: Example of SRF technical information.**

### Performance Testing\*

Method	Glass Substrate	Film Attachment	Rating	
<b>Safety Glazing</b>				
16 CFR 1201	¼" & 1/8" annealed	--	Category 2, 400 ft-lbs	
ANSI Z97.1			Class A (Unlimited), 400 ft-lbs	
<b>Impact Resistance</b>				
ASTMs E1886 / E1996	¼" tempered	IPA	Large Missile C, +/- 75 psf	
ASTM E330	3/16" tempered		+/- 100 psf	
<b>Blast Mitigation</b>			<b>Blast Load</b>	<b>Rating</b>
GSA TS01-2003 / ASTM F1642	¼" annealed	IPA	9 psi, 60 psi*msec	GSA Level 2 / ASTM "Minimal Hazard"
		IPP	7 psi, 42 psi*msec	GSA Level 2 / ASTM "Minimal Hazard"
	¼" tempered	IPA	9 psi, 60 psi*msec	GSA Level 2 / ASTM "No Hazard"
		IPP	7 psi, 42 psi*msec	GSA Level 2 / ASTM "Minimal Hazard"
	1" double pane (annealed)	IPA	10 psi, 80 psi*msec	GSA Level 2 / ASTM "No Hazard"
		IPP	9 psi, 60 psi*msec	GSA Level 2 / ASTM "Minimal Hazard"

\*Glazing systems vary. Contact 3M for more information.

### Film Properties (nominal)

Film Thickness	8 mils	Graves Area Tear Resistance (ASTM D1004)	1,200 lbs%
Film Construction	Micro-layered	Puncture-Propagation-Tear Resistance (ASTM D2582)	9.5 lbf
<b>Tensile Properties (ASTM D882)</b>		Puncture Strength (ASTM D4830)	185 lbf
Tensile Strength	32,000 psi	Abrasion Resistance (ASTM D1044)	3% Δ haze
Break Strength	255 lbs/in	Peel Strength (ASTM D3330)	6 lb/in
Elongation at Break	130%	Flammability (ASTM E84)	Class A
Yield Strength	15,000 psi	<b>Solar Properties – film applied to ¼" clear glass</b>	
Elongation at Yield	9%	Visible Light Transmitted	87%
Modulus	473 kpsi	UV Light Rejected	99.9%

Source: <http://www.3m.com>

### SRF installation methods

The SRF is applied on the inside face of a pane of glass. There is two ways to install the SRF on the windows glazing:

- Daylight application.
- Attached application, that is subdivide in wet/dry-glazed or mechanical installed.

#### Daylight installation:

- The most common and cheaper application.
- The film does not extend into the rebates of the window pane surround.
- The film is applied to the inside face of the glass with a 1 to 3mm gap between the edge of the film and the frame.
- This allows the liquid used in the application of the film to the glass surface to be pushed to the edge and wiped away, leaving a daylight area around the perimeter of the film.
- The application of SRF must, at a minimum, cover the clear area (the portion of the glass unobstructed by the frame) of the window.

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- This minimum application to the exposed glass without any means of attachment or capture within the frame, termed “daylight” installation, is commonly used for retrofitting windows. However, **the effectiveness is almost insignificant for blast protection.**

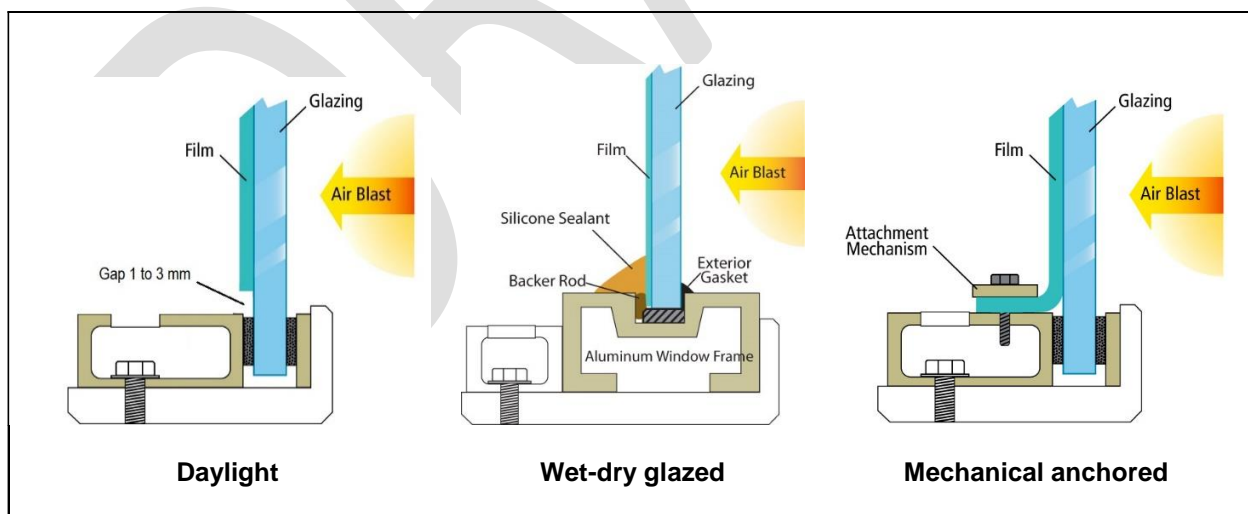
**Attached, wet/dry glazed installation:**

- The SRF is positively attached to the frame using a high strength liquid sealant such as silicone.
- Frequently used for field retrofits, the method allows the flexible frame to deform slightly, reducing glass fragments entering the building and offering more protection than the daylight installation.
- It is costlier than the daylight installation system; however is less expensive than the mechanically attached.
- Dry-glaze attachment is used with a daylight application of SRF, the system employs an extruded rubber batten which creates a factory-made triangular joint around all four perimeter sides of a window, attaching the filmed glass to the frame.

**Attached, mechanically anchored:**

- The SRF is positively attached to the frame employing screws and/or batten strips to attach the film to the frame.
- While a film may be effective in keeping glass fragments together, it may not be particularly effective in retaining the glass in the frame. Securing the film to the frame with a mechanically connected anchorage system further reduce the likelihood of the glazing system exiting the frame.
- Because additional framework is necessary, the mechanical attachment method can be less aesthetically pleasing than the wet glazed installation system.
- The installation can be limited depending of the type of frame.

**Figure 10: SRF installation methods.**

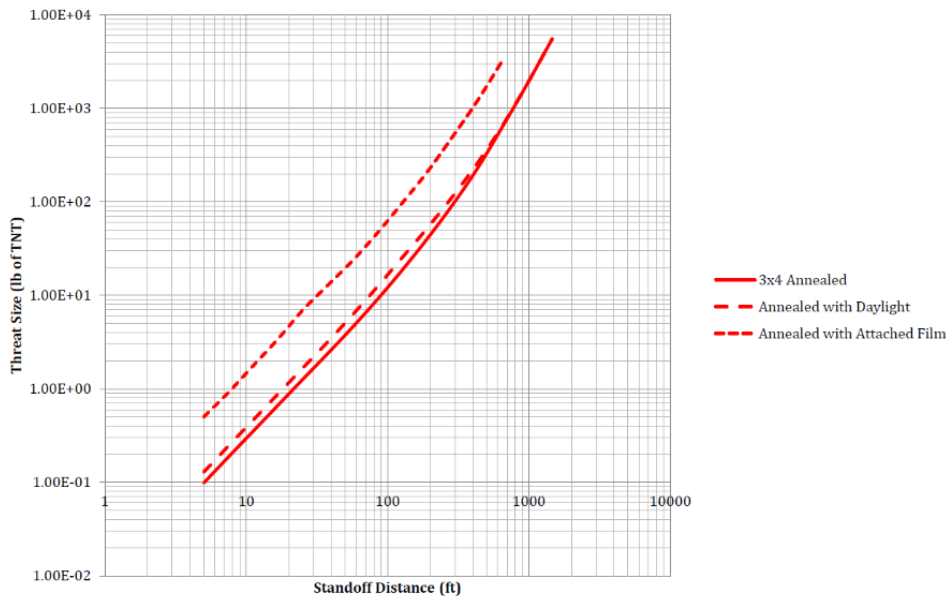


Source: <<http://www.johnsonwindowfilms.com/protective-films/anchoring-systems/>>.

The effectiveness of the SRF depends on the installation method. The attached methods are definitively more effective for blast protection than the daylight method. Figure 11 presents results of tests presented by Stone Security Engineering, an American Company specialized in blast protection. The main manufactures of safety films, such as 3M® and Madico®, also recommend attached installation instead of the daylight method.

**TIP: Daylight application** is the most common and cheaper method for SRF. It is very popular in UN premises and a good option to avoid accidental impacts and burglary attempts. However, it is not appropriate for blast protection. If a blast threat exists, the **Attached application provides more protection.**

**Figure 11: SRF effectiveness based on installation methods.**



Source: Stone Security Engineering.

**Figure 12: Installation of SRF in attached methods.**



Source: PSU files.

Given that there are many variables to be considered when evaluating the effectiveness of SRF, including the blast variables, window type, and type of protection in place, assessments of these types should be conducted using the blast evaluation tools discussed in Section 5. As a basic reference, however, the Table 2 can be used to provide a rough estimate of SRF protectiveness.

**Table 2: Examples of SRF effectiveness.**

Product	Glass	Film	Blast Load	Z	Examples of conditions		GSA Rating	ASTM Rating
					Charge	Distance		
<b>3M Scotchshield Ultra S800®</b>	Annealed 6 mm	Attached IPA (*)	9 psi 60 psi-ms	6.4	100 kg	30 m	<b>2</b>	<b>3 Minimal</b>
					50 kg	24 m		
					10 kg	14 m		
	Tempered 6 mm	Attached IPA (*)	9 psi 60 psi-ms	6.4	100 kg	30 m	<b>2</b>	<b>2 No hazard</b>
					50 kg	24 m		
					10 kg	14 m		
	Annealed 25 mm 2 pane	Attached IPA (*)	10 psi 80 psi-ms	6.0	291 kg	40 m	<b>2</b>	<b>2 No hazard</b>
					50 kg	23 m		
					10 kg	13 m		
<b>Madico SafetyShield 800®</b>	Annealed 6 mm	Daylight	12.78 psi 78.79 psi-ms	5.3	187 kg	30 m	<b>3b</b>	<b>5 Low Hazard</b>
	Annealed 6 mm	4 side structural silicon bead	12.78 psi 78.79 psi-ms	5.3	187 kg	30 m	<b>3a</b>	<b>5 Low Hazard</b>
	Annealed 6 mm	Attached FrameGard (**)	9.9 psi 64.53 psi-ms	6.1	155 kg	33 m	<b>2</b>	<b>3 Minimal</b>
					50 kg	22 m		
					10 kg	13 m		

(\*) 3M Impact Protection Adhesive Attachment System®  
(\*\*) Madico FrameGard Anchoring System

### Specifications, warrant, and replacement

The technical specification should be prepared based on the performance conditions of the SRF, not only the film properties. If specified only based on film properties, the manufacturer or vendor will provide just what were requested, but no warrant about the effectiveness of the film.

Additional requirements to be included in the specifications of the film:

- To be required an Authorized Dealer/Applicator (ADA). The ADA shall provide documentation that the ADA is authorized by the manufacturer of the film to install said window film as per the manufacturer's specifications and in accordance with specific requests as to be determined and agreed to by the customer.
- Authorization of dealership should be verified through the manufacturer.
- The ADA should provide commercial buildings reference list of 10 properties or more where the ADA has installed window film.



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- To be required to the manufacturer ensure proper quality control during production, shipping and inventory, clearly identify and label each film core with the product designation and run number.
- Proper certification of performance conditions of the film response based on acceptable international standards.
- Warrant for a minimum 10 years (some manufactures offer 12 years) from installation, and provided that the product is maintained in accordance with the window film properties.

The warrant must cover:

- Maintain Solar Reflective Properties without cracking, crazing, or peeling.
- Maintain Adhesion Properties without blistering, bubbling, or delaminating from the glass.
- Maintain Appearance without discoloration.
- Maintain Strength, Tear, and Penetration Resistant Properties as defined in product literature.

During the warrant time, the occurrence of these mentioned failures or lost of properties can be caused by bad quality of the film or bad quality of installation. In this case, if the product does not conform to the warranty, the sole and exclusive solution, to be mentioned in the technical specification is:

- Replacement of the Quantity of Film proved to be defective; and
- Provide Removal and Reapplication Labour of like quality Product free of charge.

DRAFT

## 8. WINDOW CATCHER SYSTEMS

Window catcher systems are devices spanning across a window, positively attached to the window frame or building structure, that stop the glass panel from entering an occupied space in case of an external blast. Figure 13 illustrates a test where a window was retrofitted with SRF, but the frame and anchoring were not strong enough to absorb the blast load and the entire panel is projected.

**Figure 13: Examples of rigid catcher system, anchored horizontally.**



Source: <<https://www.youtube.com/watch?v=qlfWtGWG6To>>.

The catching system will not prevent the blast effects, but only mitigate the damage caused by the window panel being propelled inside a room. Also, the windows must use laminated glass or glass retrofitted with Shatter Resistant Film (SRF). If there is no SRF on the windows, or the SRF is weak, the glass will be cracked, and the fragments will fly through the room.

There are three types of catching systems:

- Rigid Catch Systems.
- Cable Catch Systems.
- Bomb Blast Net Curtains (BBNC).

**TIP:** take attention on the type of windows opening before install windows catchers. The opening can become limited. It is necessary to consider if the windows is a escape route for fire or other emergency. Windows catchers will close the route.

**Rigid Catch Systems** consists of steel bars crossing the windows. The rigid catch bars intercept the filmed or laminated glass and disrupt its flight; however, they tend to break the dislodged glazing into smaller projectiles. Catch bars are only effective if they are distributed along the mass of the glass panel. Rigid catch systems are subject to huge forces upon impact and require considerable anchorage into a very substantial structure to prevent failure. Where either the attachments or the supporting structure is incapable of restraining the forces, the catch system will be dislodged and become part of the debris (Figure 14).

**Cable Catch Systems** consist of steel wire cables crossing the windows. Also called as energy-absorb catch system. They are used extensively to absorb significant amounts of energy upon impact, and their flexibility makes them easily adaptable to many situations. Cable systems have long been recognized as an effective means of stopping massive objects moving at high velocity. The diameter of the cable, the spacing of the strands, and the means of attachment are all critical in designing an effective catch system. An analytical simulation or a physical test is required to confirm the adequacy of the cable catch system to restrain the debris resulting from an explosive event. High-performance energy-absorbing



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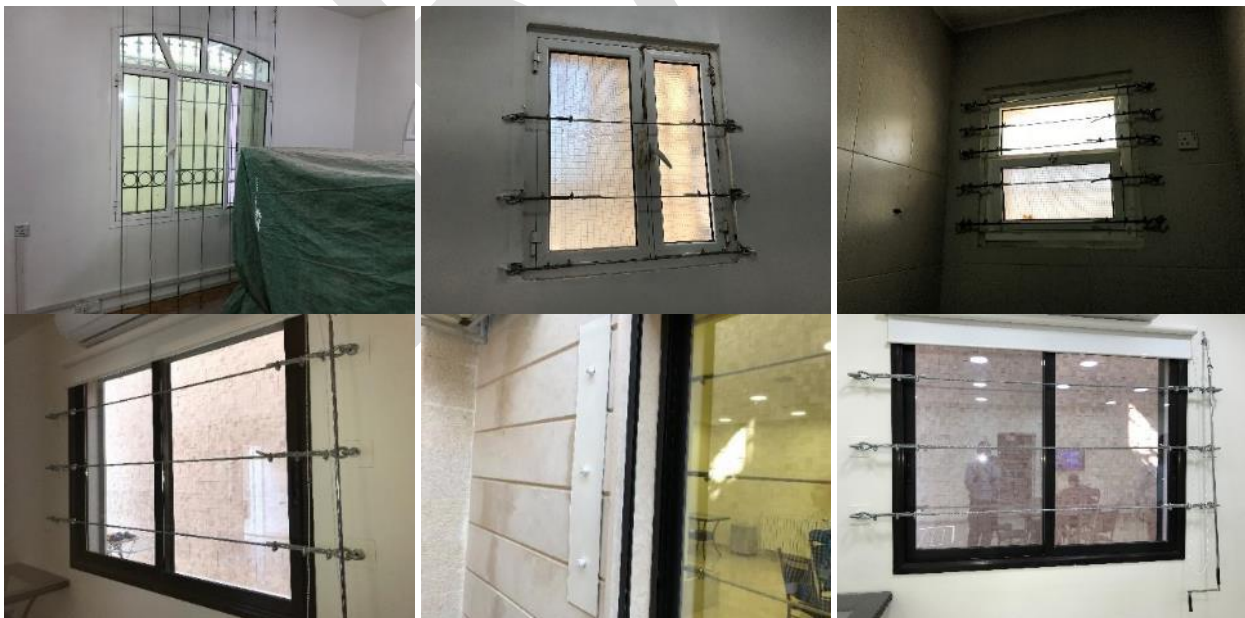
cable catch systems retain glass and frame fragments and limit the force transmitted to the supporting structure. Typical cable catchers consist of a series of 6 mm (0.25 inch) diameter stainless steel cables connected with a shock-absorbing device to an aluminium box section, which is attached to the jambs, the underside of the header, and topside of the sill (Figure 15).

**Figure 14: Examples of rigid catcher system, anchored horizontally.**



Source: PSU files.

**Figure 15: Examples of energy-absorbing cable catcher system, anchored vertically or horizontally.**



Source: PSU files.

**Bomb Blast Net Curtains (BBNC)** consist in a flexible ballistic curtain that cover the entire window. Blast curtains are affixed to the interior frame of a window opening and essentially catch the glass fragments produced by a blast wave. The debris is then deposited on the floor at the base of the window. The use of these curtains does not eliminate the possibility of glass fragments penetrating the interior of the occupied space, but instead limits the travel distance of the airborne debris. The hazard level to occupants is significantly reduced, but a person sitting directly adjacent to a window outfitted with a blast curtain may still be injured by shards of glass. The curtain will billow out about 1 meter during a blast event. The curtains may either be anchored at the top and bottom of the window frame or anchored at the top only and outfitted with a weighted hem. The curtains should be extra-long, exceeding the height of the window, with the surplus either wound around a dynamic tension retainer or stored in reservoir housing (Figure 16).

**Figure 16: Examples of blast curtains**



Source: PSU files.

**TIP:** Rigid and cable catch systems should be used in windows retrofitted with SRF. However, blast curtains should be used in windows without SRF. If SRF is used in blast curtains, the projection of the entire panel will likely rip the curtain.

### Installation of window catching systems

Although window catchers are a popular blast mitigation measure in UN, **this method is considered an improvised mitigation**, because there are no national or international standard regulating the use of window catchers, nor scientific studies proving their effectiveness.

Even the UFC 4-010-01 Minimum Antiterrorism Standards for Buildings (US DoD, 2018), states that windows retrofits incorporating alternative window treatments such as fragment retention films and blast curtains are not acceptable alternatives for new buildings or existing buildings.

The installation of these systems is based on best practices and there is no guarantee that it will increase safety and stop the windows panel projection. This is exactly the opposite of SRF, that is regulated by international standards and testing methodologies, as well as certifications of specialized testing laboratories ensuring the quality of the product.

Windows catchers are subject to huge forces upon impact and require considerable anchoring into a very substantial structure to prevent failure. Where neither the attachments nor the supporting structure can restrain the forces, the catch system will be dislodged and become part of the debris.

The main concern should be the anchoring. The windows catchers can be anchored vertically or horizontally, depending on the column or beam structure. The structure must be strong enough to absorb the impact of the entire windows flying with the blasting, as well the anchorage system used. Typically, columns, slabs and beams are the stronger structural elements in buildings, reason which is better to anchor the cables vertically, fixing them in the slab and roof beam.

The quantity of bars or cables per windows is variable, depending of the size and proportion (height and length) of the windows. As explained before, there is no standard regulating the quantity of cables or bars in a window. Best practices recommend one bar or cable each 0.5 m (fifty centimetres), horizontally or vertically from the centre of the windows.

In a research developed and tested by Stone Security Engineering and Oregon Blast Laboratory (OBL) in 2018 and submitted to the American Society of Civil Engineers,(ASCE)<sup>7</sup>, Sission and Montalva recommend a rule of thumb for designing Cable Catcher Systems to resist both window glass and frame is to use a **minimum of two cables** per window frame to better protect against window frame projectiles (Figure 17).

#### Recommendations for **rigid bars**:

- For a rigid catch system, a solid steel bar with 12 mm diameter (½ inches) with average rupture point of 50 kN or 5,000 kgf is used.
- The bar must be constructed in a unique piece, with the extremities prepared as screw to receive a nut, at least 20 mm diameter or to the bars should be a plate welded in their extremities and fixed with concrete sleeve anchor.
- The recommended plate is 5 mm thickness, 10 x 10 cm size, square or round shape, with 4 screws holes each side.

#### Recommendations for **cables**:

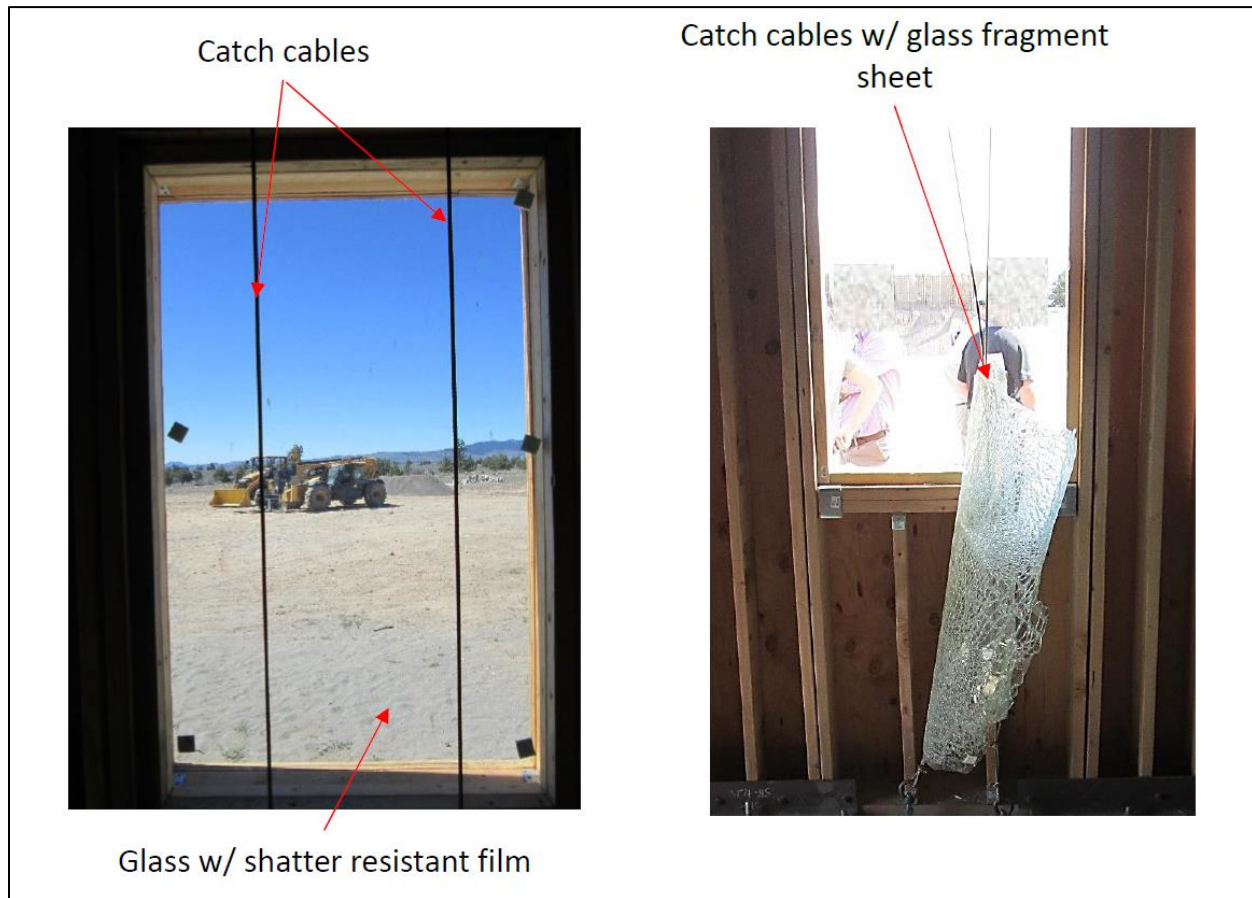
- For wire steel cables, to use at least 6 mm diameter (¼ inches) with average rupture point of 25 kN or 2,500 kgf.
- There are several characteristics of the steel wire cables, as direction strands lay, the relationship between the direction strands lay in the rope, the length along the rope, etc. As a general rule, a strand made up of a small number of large wires will be more abrasion resistant and less fatigue resistant than a strand of the same size made of many smaller wires.
- The cable catcher will work in a fixed point, without constant movement. So, steel cables with large wires are preferable because the fatigue resistance is not more essential than abrasion resistance.

The resistance of bars and cables can change based on the quality or steel. A mechanical engineer can provide detailed advising in the selection and installation of windows catchers.

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<sup>7</sup> Sisson, T & Montalva, A. **Mitigation of Glass Hazards in High Threat Environment using Cable Catch Systems**. New York: Stone Security Engineering, 2018.

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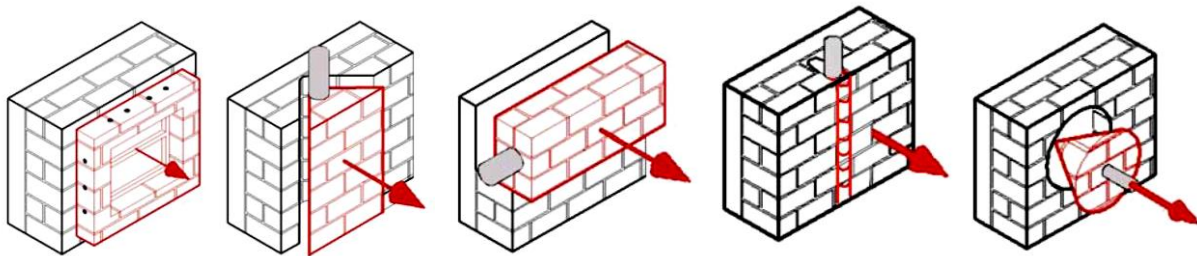
**Figure 17: Test on cable catcher system.**

**Source:** Stone Security Engineering (2018)

### Anchoring

Anchoring is a critical issue in the windows catchers. The anchoring point can be the columns (horizontally lines) or the beams (vertically lines). In some cases, the wall can be used also as anchoring point, since that the wall is strong enough to sustain the impact of windows projection in case of blast.

Figure 18 illustrates possibilities of failures that can occur in the anchorage of windows catchers, such as perimeter shear failure; masonry shear failure; anchor body shear failure; mortar joint failure; bearing failure; tensile failure.

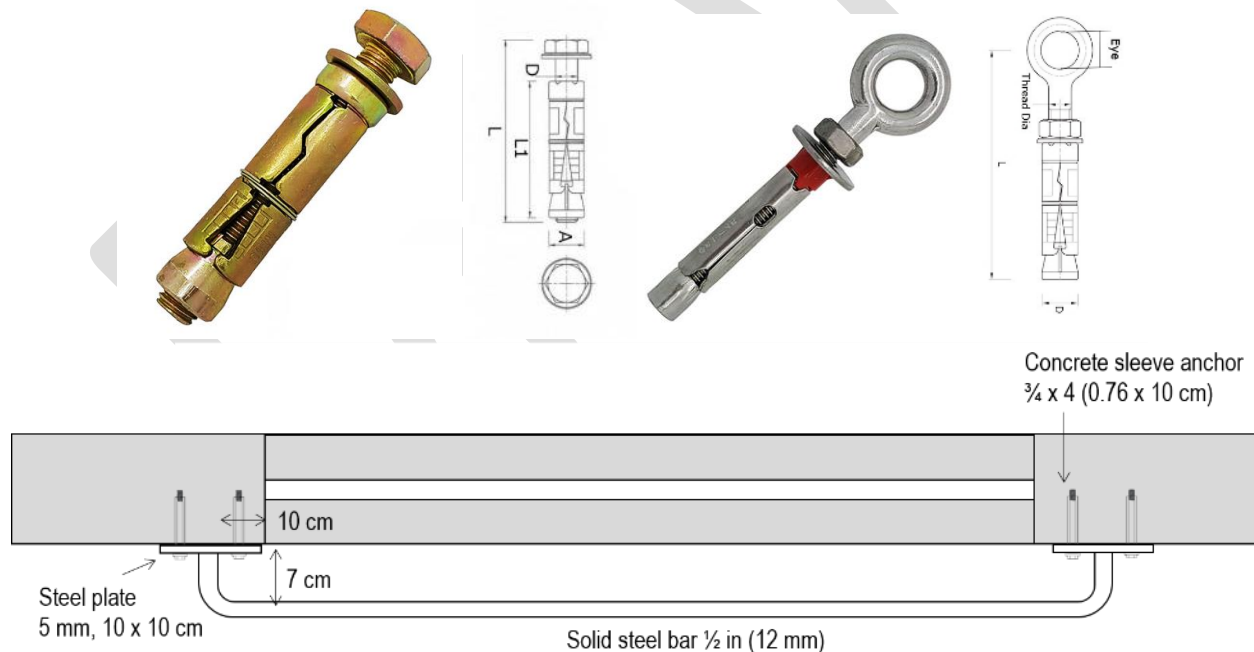
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**Figure 18: Failures on WCS anchorage.**


Source: WARD &amp; JORDAN (2018)

**Recommended anchoring for concrete walls:**

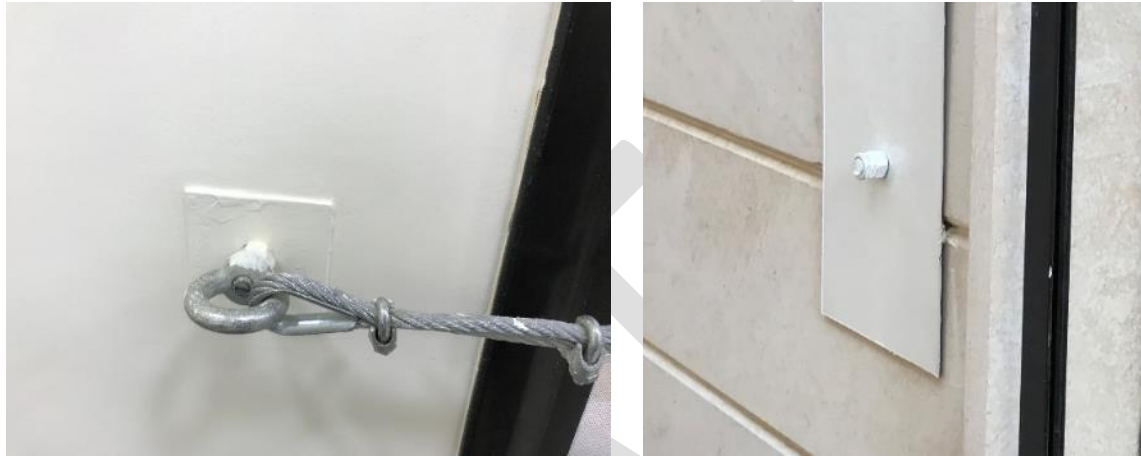
- The bars should be a plate welded in their extremities and fixed with concrete sleeve anchor, stainless steel, at least 8 mm diameter and 10 cm length.
- The cables should be fixed in steel eye bolt with anchor shield plug expansion, at least 8 mm diameter and 10 cm length.
- This anchoring system can be used in reinforced masonry walls if the contractor guarantees the same strength of the anchorage in concrete walls.

**Figure 19: Examples of concrete sleeve anchors and anchoring in concrete walls.**


Source: PSU files.

**Recommended anchorage for non-concrete walls:**

- This system is recommended to be used in masonry or cement block walls, where supposed that the walls is not strong to enough to anchor the bars.
- The bars or the eye bolt anchor should cross the wall and be reinforced with metal plates in the exterior face.
- The screw nut should be fixed on a steel plate 5 mm thickness in dimensions 15 x 15 cm, square or round shape.

**Figure 20: Examples of anchorage in non-concrete walls.**


Source: PSU files.

**TIP:** Considering that is **no standard regulating** the use of windows catchers to blast protection of windows, it is recommended to consult a mechanical or civil engineer before installations of these devices.

**TIP:** Consider retrofitting **the anchoring of the windows frame** instead to use cable catchers. It less expensive and more efficient.

## 9. CASE STUDIES ON WINDOWS PROTECTION

The following cases are actual examples of SRM measures implemented to protect windows glazing from blast threats.

### Case study 1 – The United States Mission to the United Nations (USUN)

The building is located at the corner of 1<sup>st</sup> Avenue and 45<sup>th</sup> Street in New York City and have 22 stories.

The project was led by Charles Gwathmey, from Gwathmey Siegel & Associates Architects and the building started operations on March 29, 2011.

Due to the impossibility to establish an appropriate standoff distance in Manhattan, the blast protection solution was to construct the entire building in reinforced concrete structure. The sides facing the streets are positioned at 12 m standoff, but at 6 m, there are sacrificial facades.

There are no windows in the firsts 7 floors. From the 8<sup>th</sup> floor, the windows glazing size increase with each floor.

**Figure 21: United States Mission to the United Nations**



Source: PSU files.

### Case study 2 – The AMIA building in Buenos Aires

On 18 July 1994, at 09:53 AM, a suicide bomber drove a Renault Traffic van and hit the building of the AMIA (Argentine Israelite Mutual Association), located at Calle Pasteur 633, Buenos Aires, Argentina. The VBIED was estimated with 275 kg of ANFO. 85 persons were killed and the entire building collapsed.

A new building, constructed on the same location, was positioned with a hardened standoff of 16 meters. The windows glazing was reduced and minimized in size. All glass is laminated glass, with blast resistant certification.

**Figure 22: AMIA building in Buenos Aires.**



Source: PSU files.

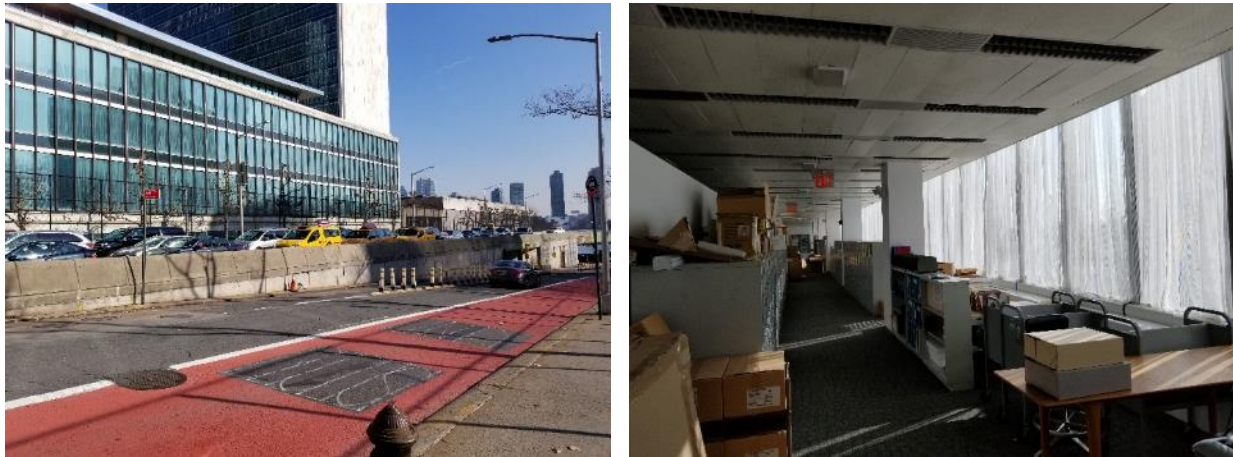
### Case study 3 – Dag Hammarskjöld Library

The Dag Hammarskjöld Library a library is located on the grounds of the UN Headquarters, on the corner of 1<sup>st</sup> Avenue and 42<sup>nd</sup> Street, New York. The building was dedicated on 16 November 1961.

The hardened standoff on the 42<sup>nd</sup> Street is 6 m. That side is a glass façade and it is not possible to avoid or to eliminate the windows glazing, due aesthetic and historical reasons.

The solution was to create an internal standoff of 4 meters. These spaces are not occupied by persons: it is used to repository for books, furniture and supporting materials for the library. The windows glazing was internally covered with bomb blast net curtains (BBNC) and installed a steel catching wall between the windows glazing and the corridors used by persons.



**Figure 23: Dag Hammarskjöld Library.**


Source: PSU files.

#### Case study 4 – UN Project in Kabul, Afghanistan

An UN Agency planned to construct a new premises inside UNOCA Compound in Kabul. Considering the large standoff and the strategic positioning inside the compound, the Agency was looking for the minimum windows glazing system necessary for that building. The baseline threat was 1,500 kg of TNT.

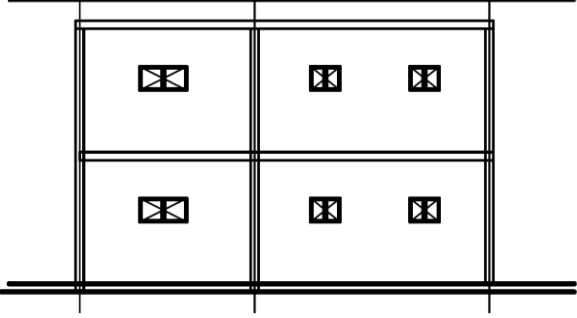
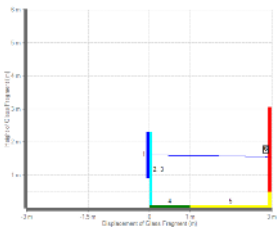
Four types of windows were analysed. PSU used a reverse calculation. Based on the planned windows, the characteristics were changed until the acceptable level of protection was obtained.

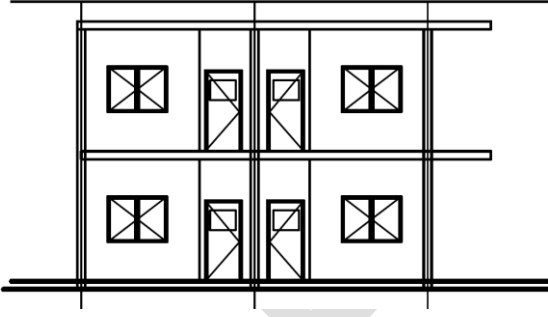
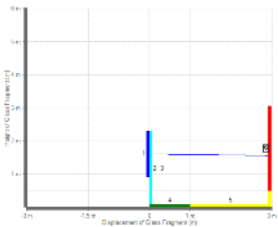
The original configuration of windows type 1, 2 and 3 presented response unacceptable (the breaking and glass shards projection can provoke severe injuries or death on UN staff). The recommended improvements were provided based on blast calculations and were:


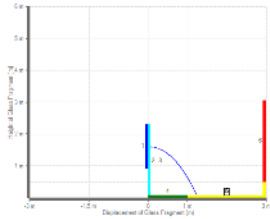
- On windows type 1 and type 3, just install SRF in attached method. This improvement was enough to obtain acceptable level of protection (LoP).
- On windows type 2, the windows glazing condition required more improvements to obtain acceptable LoP: change the glass from annealed to tempered; to change the thickness to 10 mm; and install SRF in attached method.


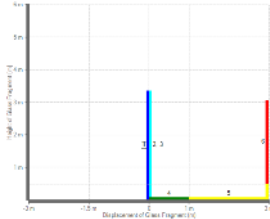
In the case of windows type 4, the calculation presented response acceptable (ASTM Level 1). No improvement in those windows was necessary and the UN agency could keep the original project.

A summary of these calculations and the windows' original design versus the recommended windows are presented in the next tables.

LPoD 1 – VBIED – WINDOWS TYPE 1			
<b>Location:</b>	Guesthouse building, external side, ground and first floors.		
	<b>Baseline threat:</b>	1,500 kg of TNT	
	<b>Standoff from LPoD:</b>	90 m	
	<b>Vertical standoff:</b>	0 m	
	<b>Angle of incidence:</b>	Incident (90°)	
	<b>Height:</b>	60 cm	
	<b>Width:</b>	75 cm	
	<b>Height above floor:</b>	155 cm	
	<b>Bite (mm)</b>	Standard (13 mm)	
	<b>Configuration:</b>	Single pane	
	<b>Frame:</b>	Aluminium	
	<b>SIMULATION 1</b>	<b>SIMULATION 2</b>	<b>RESPONSE</b>
<b>Glass type:</b>	Annealed	Annealed	
<b>Layup type:</b>	Monolithic	Monolithic	
<b>Thickness (mm):</b>	6 mm	6 mm	
<b>SRF:</b>	None	SRF attached / glazed	
<b>Catcher systems:</b>	None	None	
<b>RESPONSE LEVEL:</b>	<b>ASTM 6</b>	<b>ASTM 3</b>	
<b>UN Acceptance</b>	<b>UNACCEPTABLE</b>	<b>ACCEPTABLE</b>	

LPoD 1 – VBIED – WINDOWS TYPE 2			
<b>Location:</b>	Guesthouse building, internal side, ground and first floors.		
	<b>Baseline threat:</b>	1,500 kg of TNT	
	<b>Standoff from LPoD:</b>	90 m	
	<b>Vertical standoff:</b>	0 m	
	<b>Angle of incidence:</b>	Incident (90°)	
	<b>Height:</b>	115 cm	
	<b>Width:</b>	150 cm	
	<b>Height above floor:</b>	100 cm	
	<b>Bite (mm)</b>	Standard (13 mm)	
	<b>Configuration:</b>	Single pane	
	<b>Frame:</b>	Aluminium	
	<b>SIMULATION 1</b>	<b>SIMULATION 2</b>	<b>RESPONSE</b>
<b>Glass type:</b>	Annealed	Thermally tempered	
<b>Layup type:</b>	Monolithic	Monolithic	
<b>Thickness (mm):</b>	6 mm	10 mm	
<b>SRF:</b>	None	SRF attached / glazed	
<b>Catcher systems:</b>	None	None	
<b>RESPONSE LEVEL:</b>	<b>ASTM 6</b>	<b>ASTM 3</b>	
<b>UN Acceptance</b>	<b>UNACCEPTABLE</b>	<b>ACCEPTABLE</b>	

LPoD 1 – VBIED – WINDOWS TYPE 3			
<b>Location:</b>	Glass façade in main building, in front of LPoD 1		
	<b>Baseline threat:</b>	1,500 kg of TNT	
	<b>Standoff from LPoD:</b>	280 m	
	<b>Vertical standoff:</b>	0 m	
	<b>Angle of incidence:</b>	Incident (90°)	
	<b>Height:</b>	80 cm	
	<b>Width:</b>	160 cm	
	<b>Height above floor:</b>	110 cm	
	<b>Bite (mm)</b>	Standard (13 mm)	
	<b>Configuration:</b>	Single pane	
	<b>Frame:</b>	Aluminium	
	<b>SIMULATION 1</b>	<b>SIMULATION 2</b>	<b>RESPONSE</b>
<b>Glass type:</b>	Annealed	Annealed	
<b>Layup type:</b>	Monolithic	Monolithic	
<b>Thickness (mm):</b>	6 mm	6 mm	
<b>SRF:</b>	None	SRF attached / glazed	
<b>Catcher systems:</b>	None	None	
<b>RESPONSE LEVEL:</b>	<b>ASTM 5</b>	<b>ASTM 2</b>	
<b>UN Acceptance</b>	<b>UNACCEPTABLE</b>	<b>ACCEPTABLE</b>	

LPoD 1 – VBIED – GLASS FAÇADE			
<b>Location:</b>	Glass façade in main building, in front of LPoD 1		
	<b>Baseline threat:</b>	1,500 kg of TNT	
	<b>Standoff from LPoD:</b>	280 m	
	<b>Vertical standoff:</b>	0 m	
	<b>Angle of incidence:</b>	Incident (90°)	
	<b>Height:</b>	220 cm	
	<b>Width:</b>	300 cm	
	<b>Height above floor:</b>	0 cm	
	<b>Bite (mm)</b>	Standard (13 mm)	
	<b>Configuration:</b>	Single pane	
	<b>Frame:</b>	Metal	
	<b>SIMULATION 1</b>	<b>SIMULATION 2</b>	<b>RESPONSE</b>
<b>Glass type:</b>	Thermally tempered		
<b>Layup type:</b>	Monolithic		
<b>Thickness (mm):</b>	12 mm		
<b>SRF:</b>	None		
<b>Catcher systems:</b>	None		
<b>RESPONSE LEVEL:</b>	<b>ASTM 1</b>		
<b>UN Acceptance</b>	<b>ACCEPTABLE</b>		

**Case study 5 – Blast in Beirut, Lebanon.**

On 04 August 2020, an explosion occurred in the port of Beirut with an estimated quantity of 2,750,000 kg of Ammonium Nitrate. The explosion caused approximately 200 deaths, more than 6,000 injuries and displacement of over 300,000 persons, due to building damages over 9 km from the blast site. 24 UN Agencies located in Beirut reported damage to their premises.

The main damages in the UN buildings were in the windows. Although many premises had installed cable catchers, many of them did not work properly. Main findings, common in these damaged premises:

- The glass panels were good and resisted to the blast.
- The glass panels damaged were cracked by the deformation or displacement of the frame.
- The frames were displaced by weak anchoring, not properly designed to stand blast loads.

**Figure 24: Damages in windows after the blast in Beirut.**



Source: PSU files.

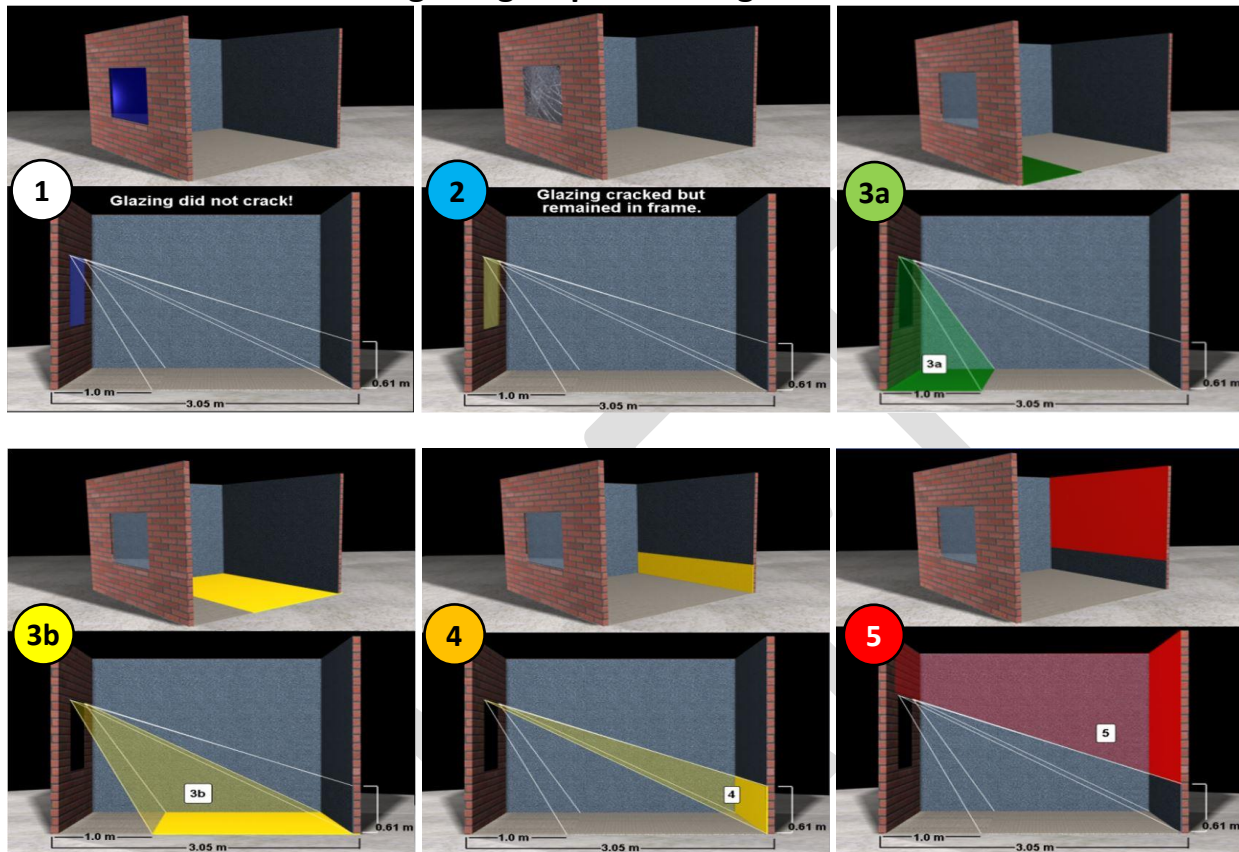
The lessons learned from this incident and the main PSU recommendation for windows protection:

***Do not look for good SRF or good cable catchers.***

***LOOK FOR GOOD WINDOWS!***

## 10. REFERENCES

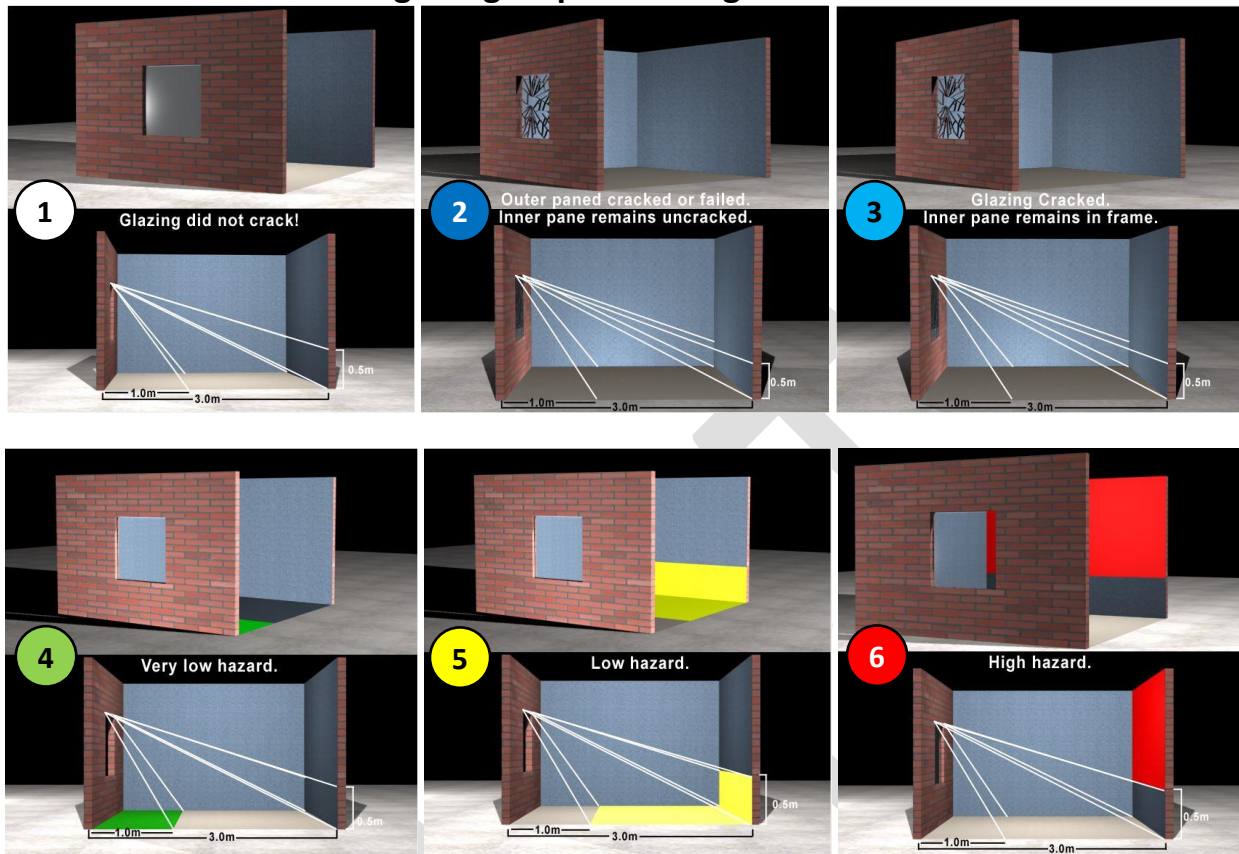
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**ANNEX 1 – SUMMARY OF STANDARDS FOR BLAST PROTECTION ON WINDOWS**
**Window glazing response using GSA standard.**


Source: Wingard® software.

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response in GSA standard
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.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. (1 m) from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft (3 m) from the window.
4	Medium	Medium	Glazing cracks. Fragments enter space and impact panel at a distance of 10 ft (3 m) from the window at a height no greater than 2 ft (0.6 m) above the floor.
5	Low	High	Glazing cracks and window system fails catastrophically. Fragments enter space impacting panel at a distance of 10 ft (3 m) from the window at a height greater than 2 ft (0.6 cm) above the floor.

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**Window glazing response using ASTM standard.**


Source: Wingard® software.

Performance Condition	Hazard Level	Description of Window Glazing Response
1	No Break	Glazing do not fracture and there is no visible damage to the glazing system.
2	No Hazard	Glazing fracture but is fully retained in the frame and the side opposite the airstblast loaded side of the glass is unbroken.
3	Minimal Hazard	Glazing fracture but is fully retained in the frame.
4	Very Low Hazard	Glazing fracture and is located within 1 m (40 in.) of the original location.
5	Low Hazard	Glazing fracture and glazing fragments fall between 1 m (40 in.) of the interior face of the specimen and 50 cm (20 in.) or less above the floor of a vertical witness panel located 3 m (120 in.).
6	High Hazard	Glazing fracture and glass fragments are projected in the opposite side of the windows located 3 m (120 in.) from the interior face of the specimen and higher than 50 cm (20 in.).