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Window Design for Blast Hazard Mitigation

Reducing damage caused by explosive blasts has become an emerging area of interest due to several high-profile incidents over the last two decades.

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A FEMA Urban Search and Rescue worker checks the stability of a window at the Pentagon following the attack on Sept. 11, 2001. FEMA photo By Jocelyn Augustino

As a result of increased terrorist activity in the past few decades, there has been growing demand for explosive blast resistance to be incorporated into the design of building structures and envelope components. Explosive blasts create additional overpressure loadings that are typically not accounted for in conventionally designed buildings. Structural design for blast resistance focuses on minimizing potential for progressive collapse through structural redundancy. The performance of building envelopes and cladding components during an explosive blast is more geared towards mitigating the hazards caused by the blast, as it has been found that many of the injuries and fatalities have been a direct result of flying glass and wall debris. Blast mitigation technologies were credited for saving many lives during the September 11 attack on the Pentagon.

The blast hazard mitigation design for windows and fenestrations specifically is of particular importance, as these façade components are typically the most vulnerable during an explosive blast. Blast resistance is typically only a requirement in federal facilities; however, it should be noted that building design for blast resistance is also a growing trend in the commercial and residential private sectors.

BACKGROUND

Immediately following the Oklahoma City bombing of the Alfred P. Murrah Federal Building on April 19, 1995,a nationwide vulnerability study was conducted by a range of federal agencies including the Federal Bureau of Investigation (FBI) and the U.S. General Services Administration (GSA). This study resulted in the Department of Justice Vulnerability Assessment Report being issued in June 1995. The report established security standards and levels for existing facilities. Prior to this, there were essentially no government-wide blast resistance standards for security for civilian federal facilities.

Following the Vulnerability Assessment Report, President Clinton signed Executive Order 12977 on Oct.18, 1995, establishing the Interagency Security Committee (ISC) consisting of 47 federal agencies and departments working in collaboration to support the functioning and security of federal facilities. In 1997, GSA issued the GSA Security Criteria to establish design standards for new federal facilities. As a supplement to the GSA Security Criteria, ISC issued their own security criteria in 2001, establishing additional requirements for glazing protection, standoff distances, vehicular access control, and security of air intake systems.

Since then, ISC has taken on a new approach to address the full spectrum of security threats through a series of documents outlining new security levels; baseline security countermeasures and implementation; risk assessment and identification; and performance measurement.

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A scene of the devastated Murrah Building following the Oklahoma City bombing, April 26, 1995. Photo Courtesy FEMA

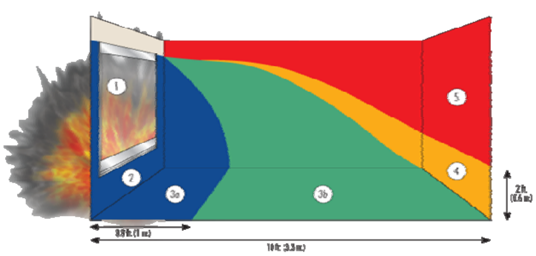
EXPLOSIVE BLAST THEORY

A stationary vehicle weapon alongside a secured perimeter of a building is the primary threat to be considered in designing for blast resistance. Design considerations for both new and existing buildings should include adequate setback and standoff distance. Yet there are obvious limitations in cases of cities and densely populated areas. A secondary threat to consider is a hand-carried weapon that may potentially be placed directly against the building envelope.

With each assumed case, both the size of the weapon and location of the threat are crucially important. In the first stage of an explosive blast, the shock wave expansion impacts the exterior envelope and structural components, creating an upward force on the floor levels as it passes through the structure. The blast wave, as it surrounds the structure, then creates both a downward pressure on the roof and an inward pressure on the sides of the building. Site and architectural variations have a major impact on a building’s vulnerability. Differing building shapes can either dissipate or accentuate an explosive blast.

Blast pressures also increase linearly with the weapon size and exponentially with the distance from the explosion. When designing to minimize damages from an explosion, it is important to balance the security concerns with other design constraints, such as efficiency, feasibility and cost.

Industry standards for blast resistance include ASTM E 1300, ASTM F 2248, ASTM F 1642, AAMA 510-06, ISO 16933, and ISO 16934. Government standards include GSA-TS01-2003, UFC 4-010-01, and UFC 4-010-02. Common testing methods outlined in these standards include shock tube, where impulse pressures are used to simulate an explosive blast, and open arena, where the test specimen is subjected to an actual explosive blast.



The various glass performance conditions established by GSA and ISC. Conditions vary with respect to the travel distance of the breakage debris. Graphic Courtesy Graham Architectural Products

RISK ASSESSMENT AND PERFORMANCE CONDITIONS

The purpose of blast resistant design is to minimize the hazards caused by a blast as opposed to preventing damages. Various damage levels should be considered, ranging from minor or non-structural to major, which may include progressive collapse. When designing for glazing, it is important to note that glass failure is not quantified in terms of whether or not breakage occurs; rather, it is defined by the hazard it creates. Performance conditions established by GSA are categorized by breakage characteristics ranging from 1, which allows no breakage, to 5, where breakage debris travels 10-ftor farther from the window.

BLAST MITIGATION TECHNOLOGIES

Various approaches may be used when designing fenestrations for blast-resistance. These include particular design of the glass or window frame components; increased anchorage of the window assembly itself; structural augmentation of the surrounding wall structure; or separate shielding systems and mechanisms designed to catch the debris. A combination of these design approaches also may be used to achieve the desired response.

One of the most common technologies currently being used is laminated glass. A range of manufacturers produce various lamination products based on desired response and performance characteristics.

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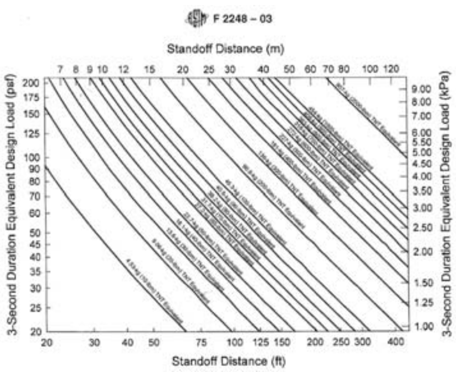
Polyvinyl butaryl layers are typically applied to the glazing layers with structural silicone sealant and in a range of interlayer configurations and thicknesses.

Consideration for the type of glass with respect to breaking strength and behavior is also important. Load transfer from the glass to the window frame and surrounding walls should be taken into account when designing for window anchorage or structural augmentation of the supporting wall. Batten bars may be used to increase the anchorage capacity of the glass itself. Steel reinforcement or tubing within the window frame can provide added resistance to blast overpressures. Many of the leading window manufactures also have specific blast-resistant window models that incorporate these technologies in a singular system.

Developing technologies include approaches that are integral to the glass composition in lieu of lamination. Engineers at the University of Missouri are developing a layer of glass fiber embedded in plastic that provides a reduced overall glass thickness, added strength to resist blasts, and transparency that many of the laminates do not have.



ASTM F 2248 graphical relationship between standoff distance, TNT charge mass, and 3-second equivalent design load.

UNIFIED FACILITIES CRITERIA

The Unified Facilities Criteria (UFC) system provides “planning, design, construction, sustainment, restoration, and modernization criteria” for all Department of Defense projects. It is accessible through the Whole Building Design Guide electronic media source, a program of the National Institute of Building Sciences.

UFC 4-010-01 DoD Minimum Antiterrorism Standards for Buildings document was most recently updated in February 2012, and includes blast resistance criteria for windows in both new and existing facilities. This criteria applies provisions for glazing, framing, connections and supporting structural elements. It includes standards for dynamic analysis, testing and explosive weights associated with respective standoff distances.

In addition to specific requirements for glass size, lamination, deflection limitation, and testing, UFC design criteria is generally based on ASTM F 2248. Given project-specific standoff distance and TNT-equivalent size, a 3-second duration equivalent static pressure load can be interpolated. This load is then used for design of the assembly frame, glazing frame bite, connections, and supporting structural elements.

THE FUTURE OF BLAST MITIGATION DESIGN

Blast mitigation design is a rapidly evolving trend in the building industry. It is the responsibility of engineers, designers and builders to account for the safety and well-being of the public. Terrorist activity is highly unpredictable and exists from a wide range of sources, leading to the increasing demand for reducing hazards in the event of an explosive blast. It is the intent of blast mitigation to control the fracture of glazing in such a way that it does not create these hazards.

New and improved technologies are continuously being researched, developed and tested. Great progress in design practice and product development has been made in the past decade, and will continue to be made going forward.

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