Blast Resistant Glazing Systems

By Jon A. Schmidt, P.E., SECB, BSCP

When an explosion occurs near an occupied facility, most of the severe non-fatal injuries suffered by those inside are generally due to flying glass from shattered windows. Examples include the terrorist bombings at the federal building in Oklahoma City (1995) and the U.S. embassies in Kenya and Tanzania (1998). Consequently, considerable effort has been invested into the development of glazing systems that offer a reduced hazard level to occupants during an exterior blast event.

Glass Types

When subjected to overpressure due to an explosion, traditional annealed glass, also known as float glass, typically breaks into large, jagged shards. These are propelled into the building at high velocity, causing serious harm to anyone with the misfortune of being nearby when the blast occurs. Tempered glass is much stronger and typically breaks into small, somewhat rounded fragments, but these "rock salt" pieces can still pose a significant risk. Today, the preferred mitigation strategy for new blast resistant glazing systems is to use laminated glass.

Already well-established in hurricane regions where windborne debris is a concern, laminated glass typically consists of two panes of annealed glass sandwiched around an interlayer of polyvinyl-butyral (PVB). When loaded by a blast, the glass still breaks, but the shards stick to the interlayer, which stretches out to absorb energy without allowing fragments to enter the building. Care must be taken to ensure that the other components of the glazing system are strong enough to withstand the dynamic reactions from the laminated glass as it responds, so that the entire pane does not separate from the wall and fly into the room. For insulating glass units, the inner pane should be of laminated glass so that the outer pane can be sacrificial.

Static Design

The Department of Defense (DoD) requires nominal ¼-inch laminated glass with a 30-mil PVB interlayer as a minimum for all windows in its inhabited buildings. DoD initially specified certain static design loads for frame members, connections, and supporting elements, but recently adopted a more detailed methodology for the design of such windows in accordance with ASTM F2248, *Standard Practice for Specifying an Equivalent 3-Second Duration Design Loading for Blast Resistant Glazing Fabricated with Laminated Glass*. This document includes a chart for determining the static wind load that corresponds to a particular combination of explosive charge size and standoff distance.

The designer uses this load to find the required nominal thickness of laminated glass in accordance with ASTM E1300, *Standard Practice for Determining Load Resistance of Glass in Buildings*. Framing members and connections are designed for a service load equal to two times the resistance of the glazing (per ASTM E1300), and deflections under this load are limited to a maximum of $^{1}/_{160}{}^{th}$ of the supported edge length. The glazing must be adhered to the frame using structural silicone sealant or adhesive glazing tape. For sealant, the bead must be at least $^{3}/_{16}$-inch thick, with a width that is at least the nominal glass thickness or ⅜-inch, whichever is larger, and not more than two times the nominal glass thickness. For tape, the width must be between two and four times the nominal glass thickness.

DoD further requires that supporting elements be designed for an ultimate load equal to eight times the resistance of the glazing (per ASTM E1300). The intent is to ensure that the ultimate capacity of the supporting elements exceeds the ultimate capacity of the glazing system connections, based on a common fastener safety factor of four. Although the resulting reactions must be used to design the connections of the supporting elements to the rest of the structure, they need not be carried any further down the load path, since the expectation is that the blast energy will be dissipated through multiple mechanisms.

Alternatives

Dynamic analysis of the glazing system for direct blast effects is generally less conservative than the static approach of ASTM F2248. Specialized software for this purpose is available to those who have a federal government contract and a legitimate need. DoD's program is called *Window Fragment Hazard Level Analysis*, or *HazL* (**https://pdc.usace.army.mil/software/hazl**), while the General Services Administration (GSA) offers *Window Glazing Analysis Response and Design*, or *WinGARD* (**http://www.oca.gsa.gov/software/wingard.php**).

Another option is to require blast testing of glazing systems in accordance with ASTM F1642, *Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings*. The designer must specify the charge size and standoff distance for an open-air arena test, or the peak pressure and positive phase impulse when a shock tube will be used. The glazing is mounted in a test frame with a witness panel located 10 feet behind it. The tested system is assigned a hazard rating based on whether the glass breaks and, if so, the locations of any fragments on the floor or the height of any penetrations of the witness panel.

Individual glazing system manufacturers are always a good resource for information about blast resistance and any unusual detailing requirements. Some even offer products intended to absorb the energy of an explosion, such that supporting elements need only be designed for typical lateral loads (e.g., wind and seismic).

Conclusion

Laminated glass has become the industry standard for blast resistant glazing systems. The hazard to building occupants from an exterior explosion is considerably reduced when this material is employed along with adequate frames, connections, and supporting elements. Structural engineers should be familiar with the associated design requirements and assist architects in preparing appropriate specifications, especially on DoD projects.▪

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