US General Services Administration
Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings

1. Introduction

This test standard is intended to ensure an adequate measure of standardization and quality assurance in the testing of window systems including but not limited to glazing, sealants, seats and seals, frames, anchorages and all attachments and/or secondary catcher or restraint mechanisms designed to mitigate the hazards from flying glass and debris. This standard is the sole test protocol by which blast resistant windows and related hazard mitigation technology and products shall be evaluated for facilities under the control and responsibility of the US General Services Administration (GSA).[1]

2. Standard Designation

GSA Test Protocol: GSA-TS01-2003
Issue Date: January 1, 2003
Distribution: There are no publication or distribution restrictions for this standard.

3. References

a. "GSA Security Criteria, Final Working Version", Building Technologies Division, Office of Property Development, Public Buildings Service, General Services Administration, October 8, 1997, For Official Use Only.
b. "ISC Security Design Criteria for New Federal Office Buildings and Major Renovation Projects", The Interagency Security Committee (ISC), May 28, 2001, For Official Use Only.

4. Terms and Definitions

The following terms and definitions are provided to facilitate the implementation of this test standard.

ANFO – A mixture of Ammonium Nitrate and Fuel Oil designed to produce explosive effects.

Annealed Glass (AG) – This is the most common glass type that is used in construction. It is also the weakest type glass and fails in large hazardous dagger-like fragments.

Bite – The depth of glass or glazing that is captured in the window frame.

Explosive – Any substance or device, which will produce upon release of its potential energy, a sudden outburst of energy thereby exerting high pressures on its surroundings.

Fully Thermally Tempered Glass (TTG) – This glass type has about four times the compressive strength of regular annealed glass. TTG is the same glass used by car manufacturers for side windows in automobiles. It is often called safety glass. The fully thermally tempered glass tends to dice into small cube like pieces upon failure.

GSA Building Security Technology Program – GSA's Office of the Chief Architect has conducted research and developed technology in order to produce the tools and methodologies required to implement blast hazard mitigation in open, public facilities. The technology transfer web site www.oca.gsa.gov presents the major products and findings of this program.

[1] Tests performed prior to January 1, 2003 that used the previous GSA test protocol, "US General Services Administration (GSA) Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings," shall be accepted as having fully complied with all requirements of this standard.

Heat Strengthened Glass (HSG) – This glass type is partially tempered. It has approximately twice the compressive strength of typical annealed glass. Like AG, HSG fails in large, dangerous shards.

Incident Pressure – The overpressure (i.e., pressure above ambient) produced by an explosion in the absence of a structure or other object. Units are typically psi.

Impulse – The area under a pressure-time waveform. Units are typically psi-msec.

Interlayer – Any material used to bond two lites of glass and/or other glazing material together to form a laminate. For annealed glass the interlayer is normally a 0.030 in. thick polyvinyl butyral (PVB). For thermally tempered glass the interlayer is normally a 0.060 in. thick PVB. Some applications use a thicker interlayer (0.090 in. and 0.120 in. are sometimes used in special applications).

Laminated Glass – Two or more plies of glass bonded together by interlayer(s). When broken, the interlayer tends to retain the glass fragments.

Lexan – Lexan®, GE's product name for polycarbonate.

Lite – Another term for a pane of glass.

Monolithic Glass – A single sheet of glass without any laminations.

Plastic Explosive – Any of a series of plastic demolition explosives with great shattering power. These normally typically contain a high percentage of a high explosive such as RDX combined with a mixture of various oils, waxes, and plasticizers. Upon manipulation these materials consolidate into a rubbery fully plasticized mass that may be kneaded and pressed into any shape. Plastic explosives have excellent mechanical and adhesive properties, and may be stretched into long strands without breakage.

Polycarbonate – Any of a family of thermoplastics marked by a high softening temperature and high impact strength. Polycarbonate is extensively used in ballistic window applications.

Primary Fragments – Fragments produced directly from the contents or casing of an explosive device.

Quasi-static – The late-time pressure produced in an internal detonation. It consists of slowly decaying shocks as well as gas pressures. The duration of the quasi-static pressure depends upon the vented area relative to the volume of the space affected. Units are typically psi.

Reflected Pressure – Pressure pulse generated when a shock front impinges onto an unyielding surface. Units are typically psi.

SDOF – Single-degree-of-freedom (SDOF) systems are commonly used for the analysis of windows under blast-induced loads. Using this approach for dynamic analysis, a given structure or window component is reduced to an "equivalent" SDOF system and its dynamic deflections can be determined. Deflections determined from the SDOF system will always be equivalent to the deflection of a specified point in the real structure or structural element. With the deflections known, basic structural analysis principles can then be used to proceed with the analysis and/or design.

Setback – The distance between where a bomb is allowed and the target.

Secondary Fragments – Fragments produced by an explosive device that are made up of the target materials or other materials other than those directly resulting from the device itself.

Security Window Film – A thin material, usually a polyester composite, that is applied to a glass surface for the purpose of controlling failure. Security window film, in the context of mitigating hazards from blast, is normally 7-mil (7/1000 in.) thick or thicker. Some manufacturers have special multi-layered products in the 4-mil thickness range that possess similar properties to normal 7-mil products. These films are normally applied to the interior surface of the glass. Security window film may be optically clear, tinted, or reflective. They may be daylight, edge-to-edge, wet glazed or mechanically attached to the window frame. Mechanical attachment normally provides the higher levels of protection.

Shock Front – A shock wave is a wave formed of a zone of extremely high pressure within a fluid, especially one such as the atmosphere that propagates through the fluid at supersonic speed, i.e., faster than the speed of sound. Shock waves are caused by the sudden, violent disturbance of a fluid, such as that created by a powerful explosion or by the supersonic flow of a fluid over a solid object. The rapid expansion of hot gases resulting from detonation of an explosive charge will form a shock wave. The leading edge of the shock wave is commonly referred to as the shock front.

Standoff – Standoff is synonymous with setback and may be used interchangeably with the term setback.

Thermally Tempered Glass – See Fully Thermally Tempered Glass.

TNT – Trinitrotoluene (TNT), a pale yellow, solid organic nitrogen compound used chiefly as an explosive, prepared by stepwise nitration of toluene. Because TNT melts at 82º C (178º F) and does not explode below 240º C (464º F), it can be melted in steam-heated vessels and poured into casings. It is relatively insensitive to shock and cannot be exploded without a detonator. For these reasons, it is one of the most favored chemical explosives and is extensively used in munitions and for demolitions.

WINGARD – WINdow Glazing Analysis Response and Design is a computer program available from the US General Services Administration (www.oca.gsa.gov) . This program is the GSA and ISC standard for the analysis and design of windows subjected to blast loads.

WINLAC – WINdow Lite Analysis Code is a computer program available from the US Department of State. Versions 4.0 and later are derivative versions of the GSA code ***WINGARD*** adapted to meet the unique requirements of the US Department of State.

5. Performance Criteria

This test method uses the ISC Security Design Criteria (Reference 3.b.) to rate the performance of window systems subjected to airblast loads. Protection and related hazard levels are categorized as a performance condition as indicated in Table 1 and Figure 1. These conditions are determined based upon the post-test location of fragments and debris relative to the original (pre-test) location of the window. Predictions of glazing response should be conducted with the computer program ***WINGARD***. The computer program ***WINLAC*** may be used for projects or tests supporting the US Department of State.

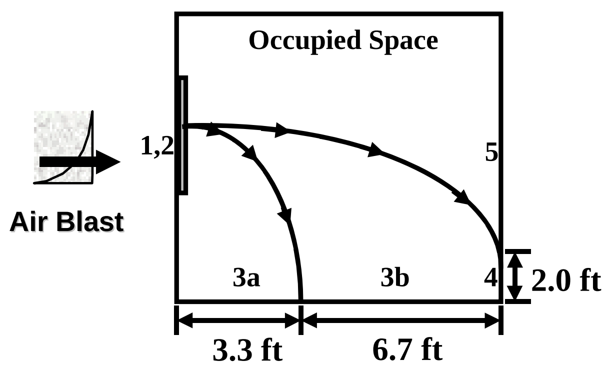

Figure 1. GSA/ISC performance conditions for window system response.

Table 1. GSA/ISC Performance Conditions for Window System Response.

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 ft. from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. 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 ft. from the window at a height no greater than 2 ft. 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 ft. from the window at a height greater than 2 ft. above the floor.

6. Requirements

6.1 Test Conductor

The test conductor shall be responsible for executing the test(s). The test conductor shall be an agency/organization that is qualified to perform such services and should be independent of the test specimen manufacturer or provider.

6.2 Methods

Tests performed using this standard may be performed as open-air high explosives events or may use shock tubes to generate the required blast pressure loadings.

6.3 Blast Loads

In order to meet GSA requirements, tests meeting this standard shall produce a dynamic blast pressure pulse that rises instantaneously to a peak overpressure, P, and decays with time to produce a positive phase impulse, I. The actual measured values of P and I shall meet or exceed those required by relevant GSA project or test specifications in accordance with applicable security design criteria. The pressure-time waveform shall have one primary positive phase peak followed by a decay in pressure. Significant secondary pressure pulses should be avoided and under no circumstances shall secondary pressure pulses exceed a value of P/4. A negative pressure phase is desired in order to replicate actual explosive loading conditions.

6.4 Test Site - Test Apparatus - Instrumentation

Tests performed under this standard may use explosive charges or shock tube. The test environment must produce the desired pressure and impulse as well as the desired pressure-time waveform characteristics. In general, explosive charges in open air tests are preferred since they generally produce complete pressure waveforms that replicate the environments of interest.

6.4.1 Test Reaction Structures and Witness Panels and Test Framing

The test reaction structures shall be enclosed structures that prevent the rapid blast pressure engulfment of the test specimens. For tests that use open air explosive charges, the test reaction structures shall be placed at appropriate distances and angles of incidence to produce the desired pressure-time loading conditions. The test reaction structures shall be non-responding relative to the test specimen(s) unless the response of the supporting reaction structure is important to demonstrating the performance of the tested specimen. If a responding support structure is required to demonstrate the performance of the specimen(s), then an appropriate responding structure should be provided. For tests using shock tubes, an enclosed reaction structure shall be provided at the end of the shock tube in a manner similar to that used for open-air explosive tests. This enclosed structure shall be designed to allow a failed window system to enter the enclosed space and land on the floor and/or impact the witness panel in order to allow determination of the performance condition as shown in Figure 1. An enclosed structure is also required so that infill pressures may be measured in the enclosed space after window failure.

A witness panel designed to record fragment and debris impacts shall be located within the enclosed reaction structure a distance not to exceed 10 ft from the interior face of the window glazing. The witness panel shall consist of a foam board with a thin aluminum sheet or paper to record penetrations and/or perforations.

Test specimens shall be mounted in frames that replicate the desired in-place conditions. For example, if the test is designed to demonstrate a system in a truly non-reacting frame then a frame shall be provided that offers sufficient resistance to load. Likewise, if a test is designed to demonstrate an energy absorbing system, then a suitable frame shall be provided.

6.4.2 Explosive Charges and Source

For tests using explosive charges, a high explosive source shall be used to generate the desired peak pressure and the positive phase impulse on the test specimen. Any type of explosive may be used as long as the desired waveform characteristics are produced and the tests are reproducible within acceptable ranges of P and I. The charge shall be hemispherical and detonated at ground level. Other charge configurations can be used. The effects of using other charge configurations must be accounted for and documented. If required to reduce the potential for ejecta debris from the crater, a blast mat, concrete pad or sand pit may be used at the discretion of the test conductor.

For tests using shock tubes, explosives or compressed gas with a rupture diaphragm may be used to generate the desired peak pressure and positive phase impulse on the test specimen. The test source must be designed so as not to overload the specimen with excess impulse. A negative pressure phase is desired in order to replicate actual explosive loading conditions.

6.4.3 Photographic Measurements

Photographic equipment shall be available to document the test. High-speed photography (500 to 1000 frames per second), normal speed video, and still photography is recommended. As minimum, there shall be at least one high-speed camera to record the response of each test specimen from an interior view. In addition, pre- and post-test still photography is required to document the condition of the tested specimens. Still photography shall be provided for both interior and exterior views.

6.4.4 Active Instrumentation and Data Acquisition

A minimum of two airblast pressure transducers shall be used on each test reaction structure to measure the pressure-time waveform acting on the exterior surface of tested specimens. A minimum of one interior pressure transducer is required in each test structure. If interior partitions are used to isolate interior pressure environments for the test specimens, an interior pressure transducer shall be used in each partitioned volume containing one or more test specimens. The airblast pressure transducers shall be capable of defining the anticipated airblast pressure-time history within the linear range of the transducer. The transducers shall have a rise/response time and resolution sufficient to capture the complete event.

Data Acquisition System (DAS)—The DAS shall consist of either an analog or digital recording system with a sufficient number of channels to accommodate the pressure transducers and any other electronic measuring devices.

6.5 Specimens

The test sponsor shall provide the test specimens. The test sponsor shall provide extra specimens in case of accidental breakage or damage during shipping. Each specimen shall be marked with the manufacturer’s name, model and serial numbers (if applicable), and date of manufacture. In addition, each specimen shall be marked to indicate the proper orientation (i.e., interior/exterior) to ensure proper mounting in the test reaction structures. The specimens shall be mounted and anchored in the reaction structures in accordance with the manufacturer’s instructions. The test conductor shall ensure that the test specimens are handled and stored in compliance with manufacturer’s instructions.

Unless intended to replicate a specific condition or designed to meet specific project requirements, the standard test window size shall be nominally 48 inches wide by 66 inches tall. The window should be mounted in the test reaction structure such that the window sill height replicates the desired in-place conditions for a particular project, or if performed as a generic test, should be approximately 24 inches off the reaction structure floor. Actual tested conditions shall be recorded and reported.

6.6 Test Measurements

6.6.1 Prior to the Test

Prior to the test, the test conductor shall:

- Record the ambient temperature within 30 minutes of test time.
- Measure and record test specimen dimensions. Measure and report actual glazing thickness.
- Photographically record the pre-test condition of the test specimens, the test frame, and the test site/apparatus configuration. This photographic record shall consist of still photographs and may include motion pictures or video.
- For tests using explosives, measure and record the test charge construction and the standoff distance from the center of the charge to the exterior face of the test specimen(s).
- For shock tube tests, measure and record the blast source construction (compressed gas and/or explosives).

6.6.2 After the Test

After the test, the test conductor shall:

- Photographically record the post-test condition of the test specimen(s), the location of any fragments/debris in the reaction structure, the test frame(s), and the test site/apparatus. This photographic record shall consist of still photographs and may include motion pictures or video.
- Record and photograph any perforations and/or penetrations of the witness panel.
- Determine and record the performance condition in accordance with the criteria shown in Table 1 and Figure 1. Dents or scratches on the witness panel paper or aluminum sheet that do not penetrate or perforate shall be noted but not counted as fragment/debris impacts for the purpose of determining the performance condition.

6.7 Reports

Upon completion of a test, the test conductor shall report the results of the test. The following mandatory information shall be reported. Additional information may be reported as appropriate.

- Test site location, test date and time.
- Description of the test site or apparatus setup. This should include a description of the explosive charge and/or other explosive shock wave source used in the test.
- Pre- and post-test description of the test specimen(s), including pertinent dimensions, construction, materials and condition.
- Pre- and post-test description of the test framing and anchorage.
- Ambient temperature for each test.
- Peak positive pressure, P, and positive phase impulse, I, recorded by each pressure transducer. Average measured pressure and impulse. Descriptions of any anomalous measurements.
- The recorded airblast pressure-time history from each pressure transducer.
- The location of any debris and/or fragments to include any perforations and/or penetrations of the witness panel.
- The performance condition for each tested specimen in accordance with Table 1 an d Figure 1.
- The test report shall contain a photographic record of the test setup. In addition, the test report shall contain detailed photographs of each test specimen prior to and following the test.

The test conductor shall keep an original of the test report on file for at least three years from submittal of the test report to the test sponsor. The test conductor shall provide a minimum of one copy of the test report plus applicable video and photographic records to the test sponsor.