National Protective Security Authority

NPSA TEST STANDARD

Explosion Resistance of Windows and Curtain Walling

Part 2: Test Method

Version 1: February 2024

Contents

Foreword

The NPSA Test Standard for the Explosion Resistance of Windows and Curtain Walling consists of two complementary documents:

Part 1: Requirements and Classification

Part 2: Test Method

This part of the Test Standard provides a method of testing and classifying windows and curtain walling systems against the criteria in Part 1.

The Test Standard does not purport to include all the necessary provisions of a contract for testing and evaluation and is limited to the methodology and specifications of the tests themselves. Users of this Test Standard and the guidance set out in it, whether test clients or test facilities, are responsible for its correct application and remain entirely responsible for compliance with any applicable law and regulations.

Compliance with this test standard does not necessarily, or of itself, confer immunity from any legal obligations and your attention is drawn to the important disclaimer on the contents page of this document.

This standard supersedes the CPNI Test Standard for Curtain Walling[1].

A detailed introduction to this test method, including its development and context, is included in Part 1 of this standard.

[1] The CPNI Test Standard: Explosion Resistance of Curtain Walling: 0ctober 2020
Part 1: Requirements and Classification
Part 2: Test Method
The standard was developed by the Defence Science and Technology Laboratory (Dstl) as part of a programme of work funded and directed by CPNI.

1 Scope

This document describes a structured testing procedure to determine the resistance of flat Windows and Curtain Walling systems installed vertically (to ± 15°) to blast loading against a range of explosion threats located externally to a structure. It also provides a structured assessment procedure to determine the hazard created by the test specimens, both internal to (behind glass) and external to the test specimen.

This test method only gives information on the performance of the test specimen subjected to explosive blast loading. It gives no information on the behaviour, when subjected to any other type of loading, of the test specimen as a whole or of individual components.

This test method is appropriate for windows and curtain walling systems including stick, unitised, semi-unitised and point-fixed walling types.

The test method has been developed for flat, vertical (to ± 15 °) test specimens with charges placed normal to the specimen. For alternative scenarios, such as testing against an oblique blast wave or testing for a situation which includes significant overhangs or recesses, the basic principles of the test method can still be applied. However, it is recommended that for these circumstances, specialist advice should be sought from a competent blast engineer[2], to develop a suitable test set up which properly represents the proposed operational setting, to ensure the design blast load is achieved and to supervise the test.

This document contains sections on test specimen loading, hazard assessment, test set up and procedure, equipment and instrumentation requirements, and reporting of results. Further relevant information is included within the Annexes.

2 Normative references

This document incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed in the bibliography.

For dated references, subsequent amendments to or revisions of any of these publications apply to this test standard only when incorporated in this standard by amendment or revision.

For undated references the latest edition of the referenced publication applies (including amendments).

[2] A competent blast engineer will be a member of the Register of Security Engineers and Specialists (www.rses.org.uk) or will be able to demonstrate a similar level of competence.

3 Terms & definitions

Clearing

The process of blast wave interaction with a finite test specimen where the blast wave moves over and around the test specimen leading to pressure differentials which induce relief waves resulting in a reduced load duration and a consequent reduction in impulse loading on the test specimen.

Curtain walling

For the purposes of this test method, curtain walling may include various types of system with a flat face and installed vertically (to ± 15 °)[3]. with glazing held in gaskets or bonded with silicone.

Curtain walling, for the purposes of this test method, includes:

Stick systems

Vertical mullions and horizontal transoms installed on metal brackets which are anchored to structural columns, beams or slabs. Each glazing pane is secured to the grid of mullions and transoms with pressure plates, toggle fixings or silicone sealant.

Unitised systems

Complete glazing units spanning the full floor height are fabricated at the factory and installed on brackets anchored to structural columns, beams or slabs.

Semi-unitised systems

Complete pre-glazed secondary glazing frames mechanically fixed to a system of pre-installed mullions and transoms.

Point-fixed systems

Glazed panes held in place with mechanical fixings attached to a structural frame installed behind the curtain wall. The fixings will generally pass through preformed holes in the glazing panes and may be individual bolt fixings or spider-type multi-point fixings.

Frame connection

The joint between the vertical (mullions) and horizontal (transoms) frame members including fixings.

Frame fixings

The components used in frame connections and frame mountings e.g. cleats, bolts and sprung fixings.

[3] From BS EN 13830:2015 Curtain Walling. Product standard.

Frame mounting

The joint between the vertical frame members and the building frame or reaction structure including fixings.

Framing system

The component parts making up the curtain walling frame within which the glazing is held, including the mullions, transoms, frame connections, frame mountings and all other components and fixings but excluding the glazing panes themselves.

Fragment

Any glazing fragment or material piece originating from the test specimen during the test which has a mass of 1.5 grams or greater.

Gauge block

A large wall with reflected pressure gauges embedded in its surface. It is used as a substitute to measure the blast pressures on the surface of a test specimen when no gauges can be embedded in it.

Gasket

A profiled rubber or neoprene strip placed between the glazing and the frame/bead to hold the glazing in place and provide a weather-tight seal.

Glazing

Glass or plastic glazing sheet material, including glass/plastic combinations.

Glazing fragment

Any glazing particle with a mass of 1.5 grams or more.

Glazing dust and slivers

Particles of glazing with a mass of less than 1.5 grams.

Glazing unit

The glazing unit fitted within the window or curtain walling frame. This may comprise:

- Single glazing with either monolithic or laminated combinations of glass.
- Double glazing combining monolithic or laminated combinations of glass.
- Triple glazing combining monolithic or laminated combinations of glass.
- Specialist glazing combinations such as forced-entry-resistant or bullet-resistant glass.

Hazard rating

A rating assessed on the performance of the Windows and Curtain Walling and its components when subjected to a specified blast load.

Ironmongery

The small metal components associated with glazing panels e.g. hinges, locks, handles and stays.

Loading category

Minimum peak reflected pressure and peak reflected specific impulse parameters to be applied at the centre of the test specimen during the test (defined in Table 1).

Pane size

The overall dimensions of the glazed portion (i.e. excluding the frame) of a glazing unit.

Pressure plate

A mechanically fixed plate covering the outer face of the joint between adjacent glazed panes.

Penetration

Any visible indentation in the face of the witness panel caused by the impact of any material detached from the test specimen by the explosion.

Rateable penetration

A fragment retained in the foam witness panel or an indentation in the witness panel, caused by the impact of material detached from the test specimen by the blast, with a cross-sectional area of more than 100 mm^2 and/or a depth of more than 2 mm measured from the surface of the witness panel.

Reaction structure

A structure with an opening in which a test specimen can be mounted. The structure must be capable of resisting the intended blast loading without deforming or moving.

Semi-infinite façade

A façade of sufficient size to ensure that clearing has no discernible effect on the loading of the structure at the point of interest compared with an infinite façade.

Significant frame component

Any frame part with a mass of 2 kilograms or more.[4]

Silicone bonding

A one- or two-part silicone mix used to bond glazing to the window or curtain walling frame forming a structural joint and sealing between the glazing and the frame, removing the requirement for a gasket and window beading or pressure plate.

Solid panel

Any non-glazed panel forming a constituent part of the window or curtain walling system.

[4] A 1 m length section of aluminium stick system extrusion weighs approximately 2 kg.

Stand-off distance

The horizontal distance from the centre of the charge to the front face of the glazed surface of the test specimen.

Test client

An individual or organisation specifying testing in accordance with this method.

Test facility

An individual or organisation conducting testing in accordance with this method.

Test specimen

The window or curtain walling specimen to be subjected to testing.

Witness panel

A panel of deformable material positioned behind the test specimen in which the impact of material forcibly detached from the test specimen during a test may be registered.

4 Loading categories

4.1 Standard loading categories

There are seven standard loading categories and a user-defined loading category that may be used to test any window curtain walling system. These are shown in Table 1.

The required loading category, against which any test specimen is to be tested, shall be specified by the test client.

Table 1: Minimum loading requirements for standard loading categories[5]

Loading Category	Peak reflected pressure, P_r (kPa)	Peak reflected specific impulse, I_r (kPa-ms)
VXR1	50	370
VXR2	65	440
VXR3	90	540
VXR4	140	690
VXR5	275	960
VXR6	185	1370
VXR7	295	1690
VXRU	User defined	User defined

The test client should ensure that the selected loading category takes due account of any blast reinforcement that may be caused at the intended site by adjacent buildings or other structures or by recesses or overhangs in the facade.

In all cases the loading category parameters are to be considered to act at the centre of the test specimen.

The test method has been developed for vertical (±15°), flat facades with the charge positioned normal to the test specimen.

[5] The pressure and impulse parameters for each load category were derived from the Kingery-Bulmash[5] equations based on a hemispherical surface burst for a semi-infinite target and have been rounded up, P_r to the next 5 kPa and I_r to the next 10 kPa-ms. The pressure and impulse parameters can be obtained using the CONWEP software tool which uses the Kingery-Bulmash equations.

4.2 User-defined loading categories

If the test client decides that none of the pre-defined loading categories is suitable (for example the loading categories do not match the operational requirement) a user-defined (VXRU) loading category should be developed.

The user-defined loading category allows this test method to be used for any project-specific loading categories, allowing the test client the flexibility to accommodate any reasonable combination of pressure and impulse test parameters, in addition to the standard categories presented in Table 1.

Any user-defined loading category shall specify the minimum peak reflected pressure and peak reflected specific impulse values to be sustained by the test specimen during the test. The values should be rounded up, P_r to the next 5 kPa and I_r to the next 10 kPa-ms.

4.3 Tolerances

In all tests it is the responsibility of the test facility to ensure, and to demonstrate, that the minimum required loading is achieved and that the test specimen is not unnecessarily overloaded within the following tolerances:

- At the centre of the test specimen, the measured value of the peak reflected pressure (P_r) parameter shall be no less than and no more than 20 % above the classification requirement figure.
- At the centre of the test specimen, the measured value of the peak reflected specific impulse (I_r) parameter shall be no less than and no more than 20 % above the classification requirement figure.
- At the upper corners of the test specimen, the peak reflected pressure (P_r) shall be no less than and no more than 20 % above the predicted value for those points on a semi-infinite facade.
- At the upper corners of the test specimen, the peak reflected specific impulse (I_r) shall be between - 10 % and + 20% of the predicted value for those points on a semi-infinite facade.

The defined blast parameters for the loading categories must be applied to the finite test specimen. Appropriate measures will therefore be required to take account of the actual test specimen and reaction structure sizes and any associated clearing effects.

In cases where a test specimen is loaded beyond the required tolerances, the hazard assessment will demonstrate the performance capability of the test specimen at the actual applied loading and can therefore be classified as a User-defined (VXRU) loading category with the relevant peak reflected pressure and peak reflected specific impulse parameters. It may also be deemed to have achieved that hazard level at the next standard loading category where both the blast parameters were exceeded.

The loading categories are broadly representative of the loading produced on a large (semi-infinite) façade by a given charge mass of TNT at a given stand-off distance, as shown in Annex A. The test classification achieved by the test specimen is against the loading category blast parameters and NOT the charge size and stand-off distance.

For atypical loadings or atypical test specimens, such as testing against an oblique blast wave or testing for a situation which includes significant overhangs or recesses, the basic principles of the test method can still be applied. In these circumstances, it is recommended that specialist advice should be sought from a competent blast engineer[2] to develop a suitable test set up to properly reflect the proposed operational setting and to supervise the test.

Unless otherwise specified by the test client the temperature of the inside and outside surfaces of the glazing in the test specimen should be at 20 °C ± 10 °C at the time of the test.

5 Hazard rating assessment process

5.1 Application

The hazard rating assessment is to be applied only to the portion of the test specimen that is supported in a manner entirely consistent with the proposed installation of the test specimen system. The test client and the test facility should agree, in advance of conducting the test, the portion of each test specimen that will be subject to the hazard rating assessment.

For example, a stick system could be tested in a three-bay configuration, to ensure that both centre mullions are loaded evenly. In this case it would be appropriate to apply the hazard assessment process to the central bay only, ignoring damage to the outer two bays.

For a unitised system it may be appropriate to test a single unit, but care must be taken to ensure that the support conditions reflect the unit in a real façade and reproduce the correct loading mechanisms.

For a semi-unitised system or a point-fixed system it may be necessary to test in a three-bay configuration to ensure that the loading of the framing system is representative.

The damage assessment should include the effects on the glazing and architectural panels, the window or curtain walling framing system and the mountings of the frame in the reaction structure.

The hazards created by the different failure modes of annealed, heat-strengthened, toughened and laminated glazing are assessed under a simple system based on the final locations and number of fragments post-test (see Figure 1) recording both internal hazard (behind glass) and external hazard.

All external and internal architectural elements, decorative items and building services that may be affected by movement of the test specimen should be included in both the test and the subsequent hazard rating assessment process. This includes such items as pressure plate capping pieces, brise-soleil, spandrel panels and service ducts.

5.2 Internal hazard

The internal hazard rating assessment is shown in Figure 1 and defined in detail in Table 2.

This assesses the hazard to personnel behind the glazing such as in an office or a retail space.

5.3 External hazard

The external hazard rating assessment is shown in Figure 1 and defined in detail in Table 3.

This assesses the hazard to personnel in front of the glazing such as in the street or open space in front of a building.

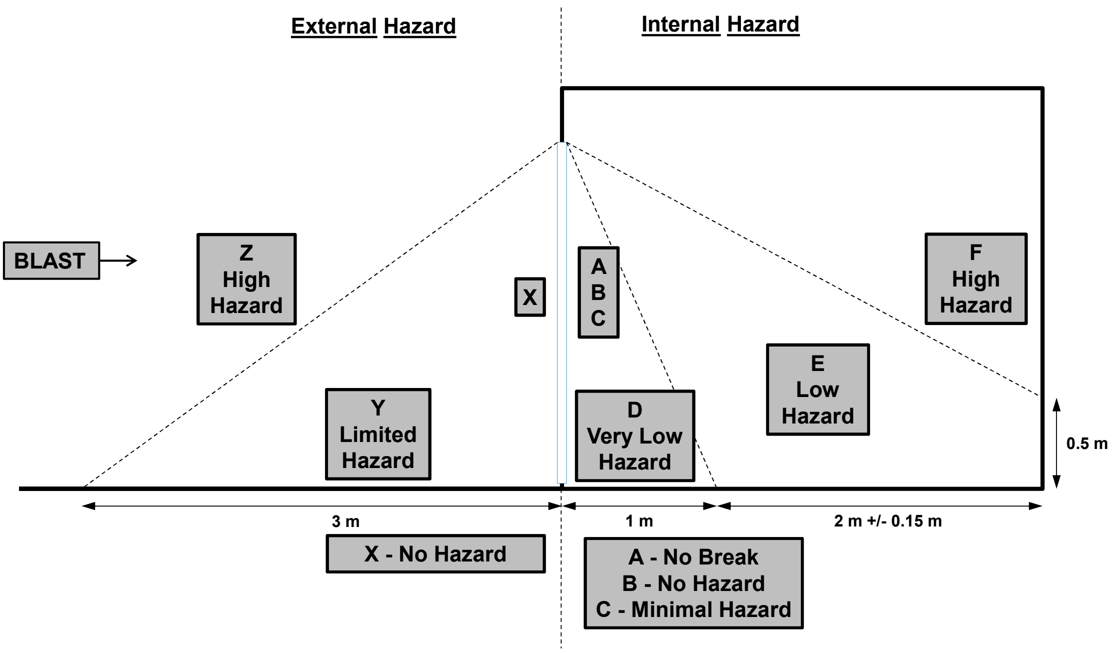

Figure 1: Illustrative cross section through a test structure showing internal and external hazard areas.

Table 2: Internal hazard rating assessment for windows and curtain walling

Hazard Rating	Definition
A **No break**	The glazing is uncracked and the framing system (including mullions, transoms and all other associated components and fixings) shows no visible signs of damage.
B **No hazard**	The glazing is cracked, but the inner, rear face leaves are fully retained in the framing system with no tears in the glazing and no material is lost from the interior surface. The framing system may show some visible signs of damage but all frame connections, ironmongery and fixings on the internal face remain attached. The mountings fixing the framing system to the reaction structure may show some distortion but remain attached.
C **Minimal hazard**	The glazing is cracked. The inner, rear face leaves are substantially retained, with, for each pane, the total length of tears plus the total length of glazing retention failure being less than 50 % of the pane perimeter.[6] (For fixed point glazing less than half the point fixings have failed.) There are no glazing fragments on the floor more than 1 m from the test specimen. Any glazing and other fragments on the floor up to 1 m from the interior face of the specimen have a total mass not exceeding 15 grams or 10 grams per m^2 glazed surface of test specimen, whichever is the greater. There are no rateable penetrations anywhere in the witness panel and The framing system may show some visible signs of damage but all frame connections, ironmongery and fixings on the internal face remain attached. The mountings fixing the framing system to the reaction structure may show some distortion but remain attached.

Note: Glazing dust and slivers are not considered in the hazard rating.

[6] There are several types of glazing retention failure including tearing of sealant, failure of the sealant bond to the glazing, glazing pulling out of gaskets and detachment of pressure plates from the frame.

D **Very low hazard**	The glazing is cracked and glazing and other fragments, or entire glazing panes, are located no further than 1 metre behind the original location of the rear face. Any glazing and other fragments on the floor between 1 m and 3 m from the interior face of the specimen have a total mass not exceeding 15 grams or 10 grams per m^2 glazed surface of test specimen, whichever is the greater. Anywhere in the witness panel, there are no more than six rateable penetrations or more than four rateable penetrations per m^2 glazed surface of test specimen, whichever is the greater. Connections within the framing system are observed to fracture or become detached and/or connection parts, ironmongery or fixings become detached. Any significant frame components travelled no further than 1 m behind the original location of the rear face. The mountings fixing the framing system to the reaction structure may show some distortion but remain attached.
E **Low hazard**	The glazing is observed to fracture and glazing and other fragments, or entire glazing panes, fall between 1 m and 3 m behind the interior face of the specimen and not more than 0.5 m above the floor at the vertical witness panel. There are 25 or fewer rateable penetrations, or fewer than 15 rateable penetrations per m^2 glazed surface of test specimen, whichever is the greater, in the area of the vertical witness panel higher than 0.5 m above the floor and none of the penetrations are more than 12 mm deep. or Connections within the framing system are observed to fracture or become detached and/or connection parts, ironmongery or fixings become detached. Any significant frame components fall between 1 m and 3 m behind the interior face of the specimen and not more than 0.5 m above the floor at the vertical witness panel. or The mountings fixing the framing system to the reaction structure may show some distortion but more than 75 % remain attached.
F **High hazard**	The glazing and framing system is observed to fracture and there are more than 25 rateable penetrations or more than 15 rateable penetrations per m^2 glazed surface of test specimen, whichever is the greater, in the part of the vertical witness panel higher than 0.5 m above the floor, or there are one or more penetrations in the same witness panel area more than 12 mm deep. or Connections within the framing system are observed to fracture or become detached and/or component parts, ironmongery or fixings become detached. Significant frame components impact the witness panel. or More than 25 % of the mountings fixing the framing system to the reaction structure fail or the whole system is projected inwards.

Table 3: External hazard rating assessment for windows and curtain walling

Hazard Rating	Definition
X **No hazard**	The glazing is uncracked and the framing system (including mullions, transoms and all other associated components and fixings) shows no visible signs of damage. All framing system components remain attached on the external face. or The glazing is cracked, but the outer, front face leaf is fully retained in the framing system. All framing system components remain attached on the external face. All glazing, cracked and uncracked, shall be retained by the framing system for a minimum of 1 hour after the test.
Y **Limited hazard**	The glazing is cracked and any glazing and other fragments on the ground up to a maximum of 3 m from the face of the specimen have a total mass not exceeding 15 grams or 10 grams per m^2 glazed surface of test specimen, whichever is the greater. All glazing, cracked or uncracked, retained in the framing system immediately after the test shall remain in place for a minimum of 1 hour after the test. and Component parts of the framing system may become detached, but no significant frame components are projected more than 3 m from the original exterior face of the test specimen.
Z **High hazard**	The glazing is cracked and/or the framing system is observed to fracture and glazing, and other fragments or component parts of the framing system are projected more than 3 m from the original test specimen surface. or Glazing and other fragments on the ground up to a maximum of 3 m from the outer face of the specimen have a total mass exceeding 15 grams or 10 grams per m^2 glazed surface of test specimen, whichever is the greater. or Significant frame components have been projected more than 3 m from the outer face of the test specimen.

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6 Facilities, equipment and instrumentation

6.1 Test facility

The test facility shall have accreditation to ISO/IEC 17025[7] with a recognised accreditation body[8] or be able to demonstrate similar competences. The accreditation should include conducting tests in accordance with this Test Standard.

The test shall be conducted using an explosive charge in a flat open area, free from loose debris and material. The area shall be of suitable size to be able to accommodate the required quantity of explosive, test specimen size(s) and stand-off distance(s).

6.2 Explosive charge

This document specifies the minimum peak reflected pressure and peak reflected specific impulse parameters required to correctly load the test specimen for a given loading category.

The explosive charge may be of any suitable explosive but shall provide the required blast parameters as specified in Table 1 and within the tolerances quoted in section 4.

6.3 Blast mat

Where there is a risk of the ground being disturbed by the explosion, a blast mat or other suitable protection shall be employed to prevent this material being projected at the test specimens and causing fragmentation damage.

6.4 Instrumentation and equipment

The instrumentation and photography plan and installation shall comply with current best practice in terms of performance, resilience and data quality and shall not interfere with the conduct of the test in any way. Gauges and data recording systems shall be calibrated, and the resulting data shall be processed in an auditable manner.

Suitable levels of redundancy should be provided within the instrumentation and data recording plan to ensure that sufficient data is collected and backed up.

[7] ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories.
[8] In the UK accreditation is usually by the United Kingdom Accreditation Service. Full details of the test facility's accreditation can be checked at www.UKAS.com

All instrumentation and equipment installed as part of the testing process shall be installed in a manner so as not to damage, affect the structural integrity or influence the performance of the test specimen as a system, or of individual specimen components, in any way, taking due account of likely movement and deflections.

Test clients should ensure that these matters are adequately covered in the terms and conditions of any contractual arrangements with the test facility engaged to conduct testing on their behalf.

6.4.1 Pressure Gauges

All tests shall include blast pressure gauges.

It is recommended that a gauge block is used to record reflected pressure-time histories. The gauge block should be rigid with a minimum of three gauges fitted flush on a flat surface located at the same stand-off distance from the blast as the test specimen and with the same face dimensions as the reaction structure (including surrounds). The positions of the centre of the gauge groups should represent the centre and top corner of the test specimen.

All gauges must be suitable for the expected incident and reflected pressure values to be recorded and any transient thermal effects. Additionally, all gauges and associated instrumentation for data capture should be optimised for the anticipated magnitudes of the expected measurements.

The pressure data shall be analysed in accordance with Annex B and compared to the required peak reflected pressure and peak reflected specific impulse values defined in Table 1.

In all cases gauges should be deployed in groups containing a minimum of 3 pressure gauges for each relevant position to ensure sufficient redundancy is available. The distance between reflective pressure gauges in a group should not exceed 200 mm.

Incident pressure gauges should be at the same height as the centre of the charge and at approximately one metre spacings. They should not be closer than 5 m to any reflecting surface, such as a test specimen structure, gauge block or other obstruction.

In general terms there are two suitable alternative methods for assessing the reflected pressure and reflected specific impulse criteria on an arena test specimen, these are shown below. If one of the alternative methods of assessment is to be used, the test facility may wish to engage a competent blast engineer[9] to review the procedure proposed.

- Use of a gauge block of a different size and/or at a different stand-off from the charge which has been previously validated against a gauge block at the same size and range as the reaction structure, providing a pressure-time history that can be used to indirectly deduce the pressure-time history experienced by the test specimen.

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[9] A competent blast engineer will be a member of the Register of Security Engineers and Specialists (www.rses.org.uk) or will be able to demonstrate a similar level of competence.

- Modelling the pressure-time history experienced by the test specimen using a software code that has been suitably validated against actual test data. This must also be validated during the test by the use of reflected pressure gauges on a gauge block at the same stand-off distance and/or an incident pressure gauge array located at the same stand-off distance as the test specimen.

It is the test facility's responsibility to agree the proposed method and its validity with the test client and to be prepared to defend and justify any proposed method should it come under scrutiny.

Further gauges may be placed to collect additional data, such as inside the reaction structure to record blast pressure leakage, as necessary. Care must be taken to ensure that such gauges do not affect the loading, test specimen performance or hazard assessment.

It is recommended that a further set of at least three pressure gauges be placed at the same stand-off distance as the test specimen to measure incident pressures. These gauges may provide additional data to enable a direct confirmation that the explosive charge has undergone a full and complete detonation and produced the required TNT equivalence.

It is the test facility's responsibility to ensure that the deployed gauge array is sufficient to record the necessary data to fully assure that the required loading category (in terms of reflected pressure and reflected specific impulse) has been achieved.

All pressure gauges shall be capable of recording the anticipated blast pressure accurately. All data acquisition systems shall have sufficient channels to record data from all pressure gauges and any other electronic measuring devices used. The data acquisition shall operate at a minimum rate of 100 kHz to reliably record peak pressures and shall be capable of recording negative phase blast loading as well. Data acquisition systems shall also include filters to exclude alias frequency effects from the data.

6.4.2 Deflection gauges

Whilst measurement of the permanent deflection is not required to assess the test specimen's performance, it can provide a useful indication of its behaviour.

Deflection gauges to record permanent and/or dynamic deflection may be deployed at the discretion of the test client.

Deflection gauges shall be installed in a manner that prevents:

- any direct effect on the performance of the test specimen system or any individual component, and
- the gauge itself causing any damage to the test specimen system or any individual component.
- Deflection gauges shall measure both peak dynamic and peak permanent deflection with an accuracy of ± 1.0 mm.

6.4.3 Photographic equipment

Adequate photographic equipment shall be provided to record the test.

Still photography is mandatory, and a photographic record shall be taken of each test specimen before and immediately after the test, irrespective of any waiting time before the hazard assessment. No displaced or damaged objects shall be moved prior to post-test photographic records being made of their position.

High-speed video (HSV) is optional. However, it is recommended that at least one external and one internal HSV view of the test specimen is obtained to assist in assessment of the test specimen's overall performance.

6.4.4 Witness panels

Witness panels shall be deployed behind each test specimen. These panels shall be parallel to the plane of the specimen and shall be placed at a horizontal distance of 3.0 m ± 0.15 m measured from the rear face of the glazed components of the test specimen to the front face of the witness panel. The witness panel shall cover the full area projected behind the specimen and extend down to the floor of the cubicle. The witness panels shall meet the following specification:

- 75 mm thick extruded polystyrene foam in accordance with BS EN 13164[10] with a compressive strength of 300 kN/m^2, that is Grade CS(10\Y)300.

- Test facilities may consider facing the front face of the polystyrene foam witness panels with either aluminium foil, not more than 0.025 mm thick, or with cartridge paper of weight between 100 and 150 g/m^2 to aid the recording of fragment impacts.

6.4.5 Temperature

The temperature of the inside and outside faces of all glazing test specimens shall be measured and recorded at the centre of each pane at the time of test. Additional measurements at other points may be taken but are not mandatory.

The ambient air temperature of the test arena is to be recorded at the time of the test.

The temperatures of the internal and external surfaces of any test specimens shall be measured and recorded immediately prior to the test.

[10] BS EN 13164 Thermal insulation products for buildings – Factory made products of extruded polystyrene foam (XPS) – Specification

7 Test plan

7.1 Test layout

A test may also be conducted with multiple test specimens in an arena with the charge at the centre. However, it is important to ensure that the correct blast load is experienced by each individual test specimen. Care shall be taken to ensure that individual test specimens do not have any detrimental effect on the loading experienced by other adjacent or nearby test specimens. Advice is available from Payne et al.[11],

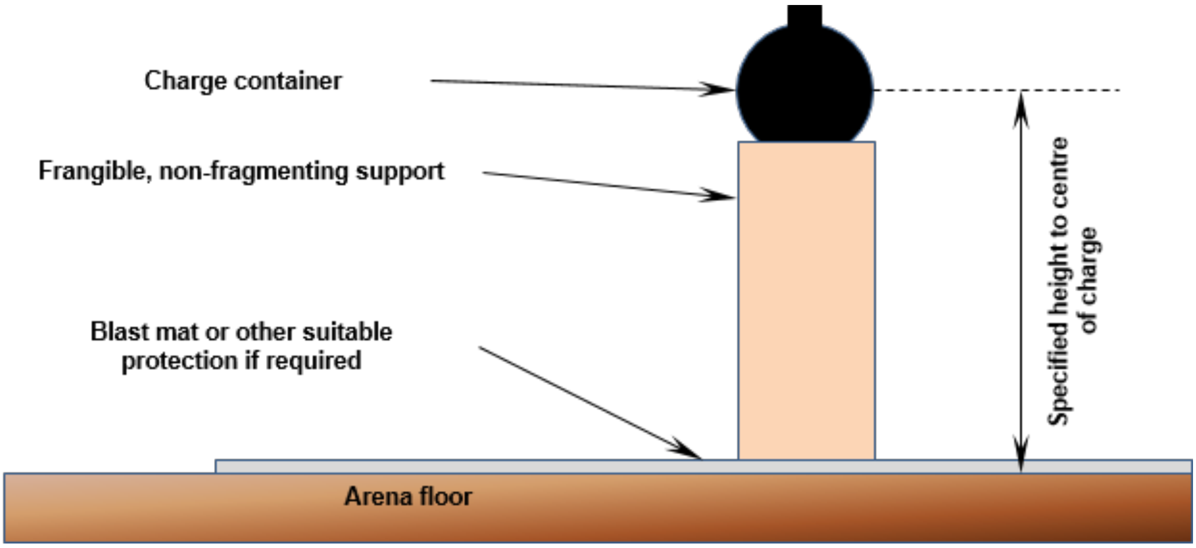

Figure 2: Charge layout

The test facility shall ensure that the charge container (if used) and the charge support are frangible. (See Fig 2).

The stand-off distance to the test specimen shall be determined by the horizontal distance from the centre of the charge to the front face of the glazing in the test specimen.

The charge shall be positioned so that it is normal to the centre of the face of the test specimen.

In general terms the required charge height is dependent on the charge mass in kg TNT_{Eq}. The charge heights should be selected to limit damage to the arena floor and losses due to interaction of the blast wave with the ground.

[11] Numerical investigation into the influence of cubicle positioning in large-scale explosive arena trials; Payne et al., International Journal of Protective Structures Vol. 7 No. 4 December 2016.

For arena tests it is recommended that for 100 kg, 200 kg and 500 kg charge sizes, minimum charge heights of 1.2 m, 1.5 m and 1.8 m respectively to the centre of the charge are used (i.e. 1.2 m for loading categories VXR1 to VXR5 and 1.8 m for categories VXR6 and VXR7).

For user defined loading categories, the height of the centre of the charge should be selected to protect the underlying arena floor construction, to minimise energy loss through cratering or other interactions with the ground and to ensure a typical blast wave profile is achieved with no significant anomalies.

Where there is a risk of loose material on the ground being disturbed by the explosion, a blast mat or other suitable protection shall be employed to prevent this material being thrown at the test specimen.

7.2 Test specimen

The test specimen must be of sufficient size to provide a realistic loading on all components within the system. (For curtain walling systems, it may not be appropriate to test a single bay as the support conditions in a rigid reaction structure may not correctly replicate the loading on mullions, transoms and frame connections in a full-size curtain walling system installation.)

Care must also be taken to ensure that the test specimen support conditions reflect the proposed installation and do not affect the test specimen's response during the test.

Windows shall be tested with frames and any infill panels as a complete system.

For curtain walling systems:

A stick system specimen shall be of a minimum size to incorporate a vertical span of one storey and a horizontal span of three bays.

The minimum test specimen for a unitised system may be a single unit, supported top and bottom.

The minimum test specimen for a point-fixed system size may be dictated by the dimensions of the supporting structure.

If the system is designed to span more than one floor, then the test specimen shall be constructed in a suitable size and manner to reflect the installation.

It is the test client's responsibility to ensure that the selected test specimen size both meets the minimum requirements and is appropriate to recreate the loading of individual components in the intended installation. The test facility may advise as to whether an assessment is possible for the size of specimen presented for the test.

Architectural elements and other items such as brise-soleil, architectural panels, service ducts and shafts or any other additional components, where they are included as part of the designed system being assessed, should be included in both the test and the subsequent hazard rating assessment process.

7.3 Reaction structure

All test specimens must be fitted within a robust reaction structure comprising an enclosed cubicle of minimum width and height defined by the test specimen system, sufficient to accommodate the necessary test specimen size, and of a sufficient depth to accommodate the correct placement of witness panels within the relevant tolerance (i.e. 3.0 m ± 0.15 m behind the rear face of the glazed components of the test specimen).

The reaction structure shall provide rigid support and prevent blast wave propagation to the rear of the test specimen within the reaction structure. It must have sufficient mass to ensure that it does not move during the test and measures shall be put in place to ensure that it can be demonstrated whether any movement has occurred during the test. All fixings, including those into the reaction structure, must be representative of those proposed for the eventual installation of the system.

The front face of the reaction structure shall be of sufficient size to ensure that the test specimen experiences the full designated blast load and that its intensity is not significantly reduced by 'clearing' of the blast wave, i.e. clearing effects will not reduce the peak reflected specific impulse experienced at the corners of the test specimen by more than 10 % of the specified value at its centre. For example, a 3.0 m wide extension to both sides of and above the test specimen has been found to be sufficient for a 4.2 m wide and 3.6 m high specimen tested at load category VXR 3.

This assessment may be made by using additional pressure gauges or by using a validated blast modelling code.

> NOTE
> If the test specimen required is larger than one storey high and three bays wide, the reaction structure will need to be strong enough to provide rigid support and prevent blast wave propagation to the rear face of the test specimen system.

7.4 Installation

The test client and the test facility should agree, in advance of conducting the test, the test specimen installation requirements to ensure the test fully represents the behaviour of the test specimen in a real installation.

The test facility shall ensure that the test specimens are stored, handled and installed in accordance with the manufacturer's instructions, specifications and drawings. These shall be kept on record for future reference.

It is the responsibility of the test facility to check and confirm that the test specimen installed reflects the drawing provided by the test client. Any change/modifications should be noted and included in the test report.

8 Test procedure

8.1 Test design

It is the test facility's responsibility to select a suitable explosive type, charge size and stand-off distance to produce the necessary blast parameters required for the test. (Clause 4.1).

The instrumentation and photographic equipment should be installed in accordance with the test plan (Clause 6.4).

The test specimen should be installed in a reaction structure in accordance with the manufacturer's fixing design. (Clause 7.3).

The face of the reaction structure must be large enough to reduce the effects of clearing (Clause 7.3).

8.2 Test conduct

The test facility shall be responsible for conducting the test including:

- Range safety during tests.
- Ensuring that any glazing fragments or debris from previous tests are cleared from the test area to ensure that a fair assessment of test specimen performance can be made.
- Ensuring that the inside of any test cubicle and/or reaction structure is cleared of any fragments from previous tests and that marked witness panels are replaced.
- Following best practice for instrumentation design, calibration and data acquisition.
- Capturing suitable and sufficient data to demonstrate the actual loading received by the test specimen(s).
- Ensuring suitable levels of redundancy within all data recording systems to ensure the necessary data is successfully collected.
- Ensuring suitable photographs (and HSV if specified) are taken to record the test.
- Conducting all the pre-test and post-test checks defined in Section 8.3 and 8.4.
- Completing suitable data analysis.
- Reporting results in accordance with Section 9.

- Meeting all statutory requirements under relevant Environmental, and Health and Safety legislation.
- Any other responsibilities delegated under the test contract.

8.3 Pre-test checks

It is the test facility's responsibility to ensure that all pre-test checks are conducted. Such checks may include but not be limited to the following:

- Check that all test specimens are as described on the manufacturer's drawings and have been correctly installed into reaction structure. Note any pre-test damage or any alterations to the standard fit of each test specimen.
- Check that all test specimens are at the correct stand-off distance from the centre of the charge to the centre of the test specimen and that test specimen faces are oriented perpendicular, on plan at ground level, to a line from the centre of the charge to the test specimen.
- Check that individual test specimens are sufficiently spaced to avoid interference with the blast loading of other adjacent test specimens.
- Check that the reaction structure has the correct witness panels fitted.
- Check that all instrumentation is correctly positioned and is functioning correctly including appropriate triggering checks.
- Set to zero the deflection gauges on wall components being tested.
- Check that all photographic equipment is functioning correctly and that video camera fields of view (if deployed) are those required.
- Check that the test area, especially around the charge and in front of the test specimens, is free from loose debris that may form damaging projectiles in the blast.
- Make a photographic record of all test specimens, including frames and any pre-test damage.
- Ensure all reaction structure access doors are correctly shut and locked. Ensure any opening components with the test specimen are in the correct test configuration.
- Check that the internal and external surface temperatures of the glass panes in the test specimen are all within the required tolerances.

- Measure and record the atmospheric conditions[12] immediately prior to the test. (Minimum meteorological data to be recorded should include external ambient air temperature, air pressure, humidity, wind speed and wind direction.)

Once the explosive charge has been brought on to the site, but prior to arming the charge, the following checks should be made:

- Confirm that the charge components are of the correct size and that the explosive(s) is of the correct type.
- Check the location of the charge and confirm that it is centrally positioned at the correct location.
- Check the stand-off(s) of the charge from the face of the test specimen(s).
- Check that the height to the centre of the charge is correct.
- Take a photographic record of the charge.

8.4 Post test

It is the test facility's responsibility to inspect the test specimen and any supporting structure to ensure that it is safe to conduct the required assessment.

When the test area is safe to enter, an initial inspection of the test specimen shall be made to record and photograph the overall condition of the test specimen and the general nature and location of any damage to the test specimen.

The test specimen shall then be assessed in detail against the internal hazard ratings (Section 5 Table 2) and the external hazard ratings (Section 5 Table 3). The glazing damage should be recorded one hour after the test to ensure any delayed damage is captured.

This assessment should record:

- The general condition of the glazing, the framing system, the component parts of the framing system and the frame mountings.
- Visible damage to and impact marks on the witness panels and their locations.
- Locations and masses of glazing fragments.
- Locations and masses of significant fragments or component parts originating from the framing system.

[12] Ambient temperature, pressure and humidity may affect overpressure data and wind speed and direction may affect fragment flight.

- The maximum permanent deflection of the component parts of the framing system (optional).

The hazard assessment is to be made only for the portion of the test specimen that is supported in a manner entirely consistent with the proposed installation of the test specimen system (e.g. only the centre bay of a three-bay stick curtain walling test specimen).

The information collected post-test shall be sufficient to award a specific Hazard Rating to the test specimen for both internal (behind glass) and external hazards.

Photographs of the test specimens shall be taken both immediately after the test and one hour after the test before removal of the test specimens.

8.5 Test conditions and tolerances

It is the responsibility of the test facility to set up the test to ensure the required blast parameters are applied to the test specimen within the relevant tolerances at the centre and corners as specified in Section 4

The following steps shall be followed to validate measurements.

- For each gauge evaluate the pressure and impulse parameters and check they both meet the required loading parameters and tolerances in Part 1 of this standard. If not, that gauge's results are not acceptable.
- For each group of gauges, calculate separately the mean value of the pressure and impulse parameters for gauges with acceptable readings.

  .
- Pressure-time history records shall be acceptable only if both P and I values for that gauge are within ± 5 % of the mean results for the gauges (minimum of 3) at that location.
- At each location there must be at least two acceptable pressure-time history records for the test results and classification to be valid.

When an alternative method has been agreed (see Clause 6.4.1), the same steps shall be followed except that the required loading parameters for the gauge block will have been derived to ensure that the test specimen receives the blast loading parameters required by Part 1 of this test standard.

The temperatures of the internal and external surfaces of the glazing panes in the test specimen shall be 20 °C ± 10 °C unless otherwise specified by the test client[13].

[13] It may be necessary to shield the test specimen or use other measures to avoid the temperature of the glazing panes being raised by solar radiation.

9 Test report

9.1 Mandatory information

Upon completion of a test, a “Commercial in Confidence”, written test report shall be provided by the test facility. The original copy of the test report shall be furnished to the client for the test.

The testing facility shall keep a record copy of the test report, along with relevant supplementary information, on file for a recommended minimum period of 10 years (see section 9.2).

The following information shall be reported.

Test facility information

- Name and address of the facility conducting the test.
- Details of the test facility’s accreditation to conduct the test.[14]

Test specimen information:

- Description of the test specimens, including pertinent dimensions, construction and materials.
- Manufacturer’s name or trademark.
- Product name, type and serial number.
- Manufacturer’s specification and/or drawings sufficient to accurately describe the test specimen. (This should include details, part numbers and sources of individual components and the amendment state of drawings).
- Description and details of any associated fixtures, fittings or framing supplied with the test specimens or used during the testing process.
- Complete description of the condition of the specimens as installed.
- Size, type and lay up details of any glazed elements.
- Description and details of the connections between the test specimen and the reaction structure.
- Any additional technical drawings and material specifications.

Test Plan

- Statement of test requirement:

[14] This can be demonstrated by being accredited to ISO/IEC 17025[6] with a recognised accreditation organisation such as UKAS. The accreditation should include this standard.

  - Blast parameter requirements at the centre of the test specimen.
  - Test specimen temperature criteria
- Statement of design of reaction structure.
- Statement of instrumentation and video locations.
- Statement of charge size, explosive type and position
- Statement of method of analysis to develop/validate loading parameters.
- If the hazard rating is based on only part of the test specimen (see Section 7.2), a statement explaining which parts of the test specimen are to be assessed.

Test set-up information

- Date and time of the test(s).
- Number of specimens tested.
- Horizontal distance from the centre of the charge to the outer glass face of the test specimen.
- Height of bottom edge of test specimen.
- Orientation of the test specimen with respect to a line drawn from the centre of the explosive charge to the centre of the reaction structure (if other than normal).
- Number and locations of all blast pressure transducers (incident and reflected).
- Number and locations of high-speed video cameras (where used).
- All relevant temperature measurements at the point of test, including atmospheric ambient air temperature.
- Elevation of the test site above sea level.

Test results

- Assessment of the blast parameters achieved at the centre of the test specimen and the top corners of the test specimen.
- Hazard rating of the test specimen with supporting data.
- The temperatures of the inside and outside faces of the glass panes in the test specimen recorded at the centre of each pane.

Supporting test data

- Peak positive phase reflected pressure(s), reflected specific impulse(s) and duration(s) measured on the reaction structure or the gauge block representing the reaction structure.

- Where gauges are neither installed on the reaction structure nor on a suitably sized gauge block, the test facility must provide the same data developed via an appropriately validated method of recording the reflected pressure-time history to infer a reflected pressure-time history and must additionally provide details of both the method and its associated validation process.
- Mean peak positive phase reflected pressure and reflected specific impulse and duration showing the computations employed (see Annex B) to derive the blast parameters experienced at the centre of the test specimen (see Annex A) on each test specimen for comparison with the relevant classification.
- Data from pressure gauges or calculations to demonstrate that the pressure and impulse parameters at the corners of the test specimen meet the required tolerances and details of the method used.
- If specified, incident peak positive phase pressure(s), specific impulse(s) and duration(s) measured at the same stand-off as the distance from the charge to the test specimen.
- Recorded blast pressure history from each pressure gauge.
- Condition and location of all parts of the test specimen, both immediately following the test and one hour after the test, including the length and location of any openings made in the specimen during the test and whether the test specimen was retained in the reaction structure.
- Glazing fragment data collected.
- Details of fragments of other materials.
- Damage to the witness panels resulting from the blast, including the location and height of any penetrations or indentations.

Photographs

- A photographic record of the test set-up as described.
- Detailed photographs of each test specimen following the test.
- A labelling system to ensure that the specimens included in post-test photographs can be clearly identified.

9.2 Supplementary information

The test facility may attach to the test report the following information, where applicable:

- Selected stills from high-speed videos that show the response of the system (as appropriate).
- High-speed video footage (as appropriate).
- Recorded deflections and locations (as appropriate).
- Additional technical drawings and material specifications.

The test facility shall maintain a full and detailed record of testing including a list of relevant drawings and material specifications and their respective revision states that accurately reflects the test specimens as tested.

It is recommended that the test facility should maintain such records for a minimum period of 10 years.

The test client should supply to their customers all pertinent testing, certification and specification data relating to systems tested in accordance with this test method, as necessary to meet the requirements of the Construction (Design and Management) Regulations (CDM) 2015.

10 Dissemination and publication of results

Should the manufacturer wish, products may be considered for inclusion in a classified government catalogue listing security equipment that has been successfully tested against certain test criteria.

To initiate this, written test reports for all tests carried out on products, and their model identifier together with a covering letter, should be sent by the manufacturer to NPSA at cse@npsa.gov.uk.

References

1. CPNI Test Standard – October 2020, Explosion resistance of curtain walling
    a. Part 1, Requirements and classification
    b. Part 2, Test method
2. BS EN 13123 – 2:2004, Windows, doors, and shutters – Explosion Resistance – Requirements and Classification – Part 2: Range Test.
3. BS EN 13124 – 2:2004, Windows, doors, and shutters – Explosion Resistance – Test Method – Part 2: Range Test.
4. BS EN 13541 – 2012, Glass in building -Testing and classification of resistance against explosion pressure
5. ISO 16933:2007, Glass in building – Explosion-resistant security glazing – Test and classification for arena air-blast loading.
6. GSA-TS01-2003, US General Services Administration, Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings.
7. JRC 98372 Recommendations for the improvement of existing European norms for testing the resistance of windows and glazed façades to explosive effects, ERNCIP Resistance of Structures to Explosion Effects Thematic Group, 2015.
8. ASTM International, F 1642-17, Standard Test Method for Glazing and Glazing Systems Subject to Air-blast Loadings.
9. ASTM International, F 2912-17, Standard Specification for Glazing and Glazing Systems Subject to Air-blast Loadings.
10. ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories.
11. C Kingery and G Bulmash, Airblast Parameters from TNT Spherical Air Burst and Hemispherical Surface Burst, ARBRL-TR-02555, Ballistic Research Laboratory, 1984.
12. Conventional Weapons Effects Programme (ConWEP) software by D Hyde, ConWEP v. 2.1.0.8, Geotechnical/Structures Laboratory, USACE Engineer Research & Development Center, Vicksburg, Mississippi.

Annex A: Nominal charge masses and standoff distances

(Informative)

The standard loading categories VXR1 to VXR5 represent the loading produced on a large (semi-infinite) facade[15] by a 100 kg charge detonated at a height to the centre of the charge of 1.2 m at a number of given stand-off distances. The standard loading categories VXR6 and VXR7 represent the loadings produced on a large facade by a 500 kg charge detonated at a height to the centre of the charge of 1.8 m.

These nominal charge masses and stand-off distances are listed for information in Table A.1.

However, it is important to recognise that the defined blast parameters for the standard loading categories (see Table 1) must be achieved at the centre of the test specimen whilst taking account of the specimen size and any associated clearing effects.

The test facility, therefore, is required to apply the relevant loading category blast parameters and not use the nominal charge mass and stand-off.

Table A.1: Standard loading categories and representative charge masses and stand-off distances[16]

Loading category	Nominal charge mass[17] (kg TNT_{Eq})	Nominal stand-off distance (m)
VXR1	100	34
VXR2	100	30
VXR3	100	25
VXR4	100	20
VXR5	100	15
VXR6	500	30
VXR7	500	25

[15] Large (or a semi-infinite) façade indicates a façade of sufficient size to ensure that clearing has no discernible effect on the loading of the structure at the point of interest (Section 3. Terms & Definitions).

[16] Charge size and stand-off data are based on blast calculations conducted at Standard Temperature and Pressure (STP)

[17] Representative charge sizes are quoted as the charge mass in kg of TNT equivalent (TNT_{Eq})

For information the loading categories are shown below for:

- ISO 16933:2007 Glass in building – Explosion-resistant security glazing – Test and classification for arena air-blast loading..
- BS EN 13123-1:2001 Windows, doors and shutters. Explosion resistance. Requirements and classification - Shock tube
- ISO 16934:2007 Glass in building – Explosion-resistant security glazing – Test and classification for shock tube loading

The current edition of BS EN 13123-2 for arena testing makes no provision for testing using VBIED sized charges. In ISO 16933, which also covers arena testing, the blast parameters for the EXV loading categories represent a 100 kg charge at selected stand-off distances loading a 1.1 m by 0.9 m glass test specimen mounted in a 3 m by 3 m cubicle. This cubicle size provides sufficient extensions round the relatively small window specified to produce only a small reduction in impulse caused by clearing effects. Annex C of the ISO presents approximate charge masses and stand-off distances which will produce the same blast parameters for a large facade.

Table A.2: Standard ISO 16933 loading categories and nominal charge masses and stand-off distances[18] for arena tests using large (VBIED) charges

Loading category	Nominal charge mass[19] (kg TNT_{Eq})	Nominal stand-off distance (m)
EXV 45(X)	30	32
EXV 33(X)	30	23
EXV 25(X)	40	19
EXV 19(X)	64	17
EXV 15(X)	80	14.4
EXV 12(X)	100	12.4
EXV 10(X)	125	11

For shock tube tests, both the BS EN and ISO standards specify the peak pressure and peak positive specific impulse parameters for each loading category and provide in Annexes, for information only, approximate charge mass and stand-off distance pairs.

[18] Charge size and stand-off data is based on blast calculations conducted at Standard Temperature and Pressure (STP)
[19] Representative charge sizes are quoted as the charge mass in kg of TNT equivalent (TNT_{Eq})

In general, shock tubes provide blast loadings which represent larger charges at greater distances than are usually required for mitigating the effects of VBIEDs. The equivalent charge mass and stand-off distance pairs for the EPR loading categories in BS EN 13123-1 are shown below.

In ISO 16934, which was developed from BS EN 13123-1, the ER (small charge) loadings are similar but two extra loadings were introduced. Annex C of the ISO presents approximate charge sizes and stand-off distances which will produce the same blast parameters for a large facade. In both ISO and BS EN, two mass/stand-off pairs for ER200 (EPR4) are provided.

Table A.3: Standard loading categories and nominal charge mass and stand-off distancers[20] for shock tube tests representing large (VBIED) charges

Loading category	Nominal charge mass[21] ($kg\ TNT_{Eq}$)	Nominal stand-off distance (m)
ER 30	30	33
ER 50 (EPR1)	100	34
ER 70	160	33
ER 100 (EPR2)	500	29
ER 150 (EPR3)	1,000	41
ER 200 (EPR4)	2,000	46
ER 200 (EPR4)	2,500	49

[20] Charge size and stand-off data is based on blast calculations conducted at Standard Temperature and Pressure (STP)

[21] Representative charge sizes are quoted as the charge mass in kg of TNT equivalent (TNT_{Eq})

Annex B: Derivation of blast parameters

B.1 Scope

This Annex sets out the procedures to be followed by the test facility to achieve consistent measurement and derivation of the test blast parameters for comparison against the minimum loading requirements defined in NPSA Test Standard– Explosion Resistance of Windows and Curtain Walling – Part 1 - Requirements and Classification (2024) Section 6, Table 1.

B.2 Symbols

$\mathbf{t_A}$	Time of arrival	$\mathbf{t_+}$	Duration of positive phase
$\mathbf{p_0}$	Ambient pressure	$\mathbf{i_-}$	Negative specific impulse i_-
p	Pressure	$\mathbf{t_-}$	Duration of negative phase
$\mathbf{p_{max}}$	Peak positive reflected pressure	**tΔ**	Positive duration of theoretical triangular shaped pressure profile based on $\mathbf{p_{max}}$ and $\mathbf{i_+}$
$\mathbf{i_+}$	Positive specific impulse	$\mathbf{i_+}$	Positive specific impulse, calculated from measured test values
p(t)	Pressure, above ambient pressure, at time **t**	$\mathbf{t_+}$	Positive phase duration derived from measured test values
$\mathbf{p_c}$	Classification peak pressure		
$\mathbf{i_{+c}}$	Classification positive phase specific impulse	$\mathbf{t_\Delta}$	Triangular duration calculated from $\mathbf{p_{max}}$ and $\mathbf{i_+}$

B.3 Units

Pressure	kPa	(1 kPa = 1 kN/m^2)
Duration	ms	
Impulse	kPa-ms	(The area enclosed under the pressure-time curve.)

B.4 Blast shock-wave characteristics

A blast wave can be generated by detonation of a high explosive. This results in a sudden release of energy that causes the air to be highly compressed and driven at supersonic speeds, during which air molecules cannot respond as they would to a normal input of energy. As a result, the air "shocks up" to form a blast wave.

The blast wave is characterised at any given location by an instantaneous rise in pressure followed by a decay over a time called the positive phase duration. See Figure B.1.

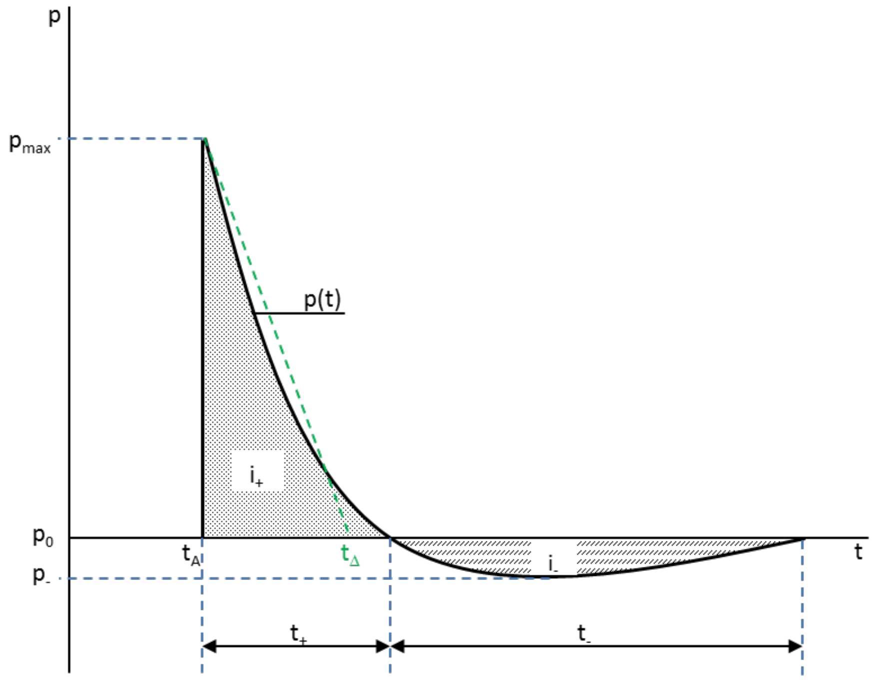

Figure B.1: Idealised pressure-time record for a blast wave.

B.5 Mathematical relationships

The relationship between the parameters $\mathbf{p_{max}}$, $\mathbf{i_+}$, $\mathbf{t_+}$ and **tΔ** can be expressed as functions of the exponential decay shape of the idealised pressure-time trace using the following formulae:

The modified Friedlander equation:

$$\mathbf{p(t) = p_{max} \cdot \left(1 - \frac{t}{t_+}\right) \cdot e^{\left(-A \cdot \frac{t}{t_+}\right)}}$$

Where **A** is the decay coefficient or form parameter.

The integration of the modified Friedlander equation to express the calculated impulse, which is the area under the positive phase of the pressure-time trace, as:

$$\mathbf{i_+ = p_{max} \cdot t_+ \cdot \left(\frac{1}{A} - \frac{1}{A^2} \cdot (1 - e^{-A})\right)}$$

The equivalent triangular duration for the limiting case when the value of the decay coefficient, **A**, would be zero and the trace would be a straight line. This idealised case is often used when carrying out response calculations:

$$\mathbf{t_\Delta = 2 \cdot \frac{i_+}{p_{max}}}$$

B.6 Classification of blast pulses

Figure C.1 illustrates the idealised shape of a blast pulse. The classification of a blast pressure pulse can be calculated by using the values of $\mathbf{p_c}$ and $\mathbf{i_{+c}}$ which are the minimum permissible to achieve the appropriate classification and are related to each other and $\mathbf{t_{+c}}$ by the same formulae as in clause C.5:

$$\mathbf{p(t) = p_c \cdot \left(1 - \frac{t}{t_{+c}}\right) \cdot e^{\left(-A \cdot \frac{t}{t_{+c}}\right)}}$$

$$\mathbf{i_{+c} = p_c \cdot t_{+c} \cdot \left(\frac{1}{A} - \frac{1}{A^2} \cdot (1 - e^{-A})\right)}$$

Different shape classification pulses may similarly be derived ranging from sharper curves having a steeper initial decay rate but longer positive duration corresponding to **A** = 4 down to the limiting case of a straight line when **A** = 0 where:

$$\mathbf{t_{+c}} = \mathbf{t_{sc}} = \mathbf{2} \cdot \frac{\mathbf{i_{+c}}}{\mathbf{p_c}}$$

In all cases the values of all three blast parameters, peak pressure, impulse and duration and the value of the decay coefficient **A** shall comply with clause B.5.

B.7 Method of recording test parameters

The test blast parameters shall be obtained using electronic recording equipment capable of recording and reproducing on screen and in the form of a hard copy visual trace the pressure time history of the blast pulse in steps of not more than 0.01 ms (100 kHz). This shall be done for each blast gauge receiving the blast pressure experienced by the attack face of the test specimen. The pressure history shall be recorded and reproducible over the positive phase period in detail and also over the subsequent period of not less than 10 times the duration of the positive phase. By agreement with the test client the equipment may incorporate devices to filter and/or smooth the pressure history to a mean trace. If such devices are used details of the method and effect of filtering or smoothing shall be stated in the test report.

B.8 Criteria for compliance of the pressure wave

A pressure wave in accordance with the classification will be achieved if the measured parameters are within the limits specified in Section 6 and Table 1.

B.9 Procedure for verifying compliance of the pressure wave

Measured and recorded pressure time traces may follow an irregular shape, therefore it is necessary to carry out a recognised procedure, such as that shown below, in order to prove compliance with the classification parameters:

- Draw a smooth curve through the trace to produce a mean pressure-time trace that most closely matches the mean path of the recorded trace. In the first instance this may be done by eye. Alternatively, a best fit curve may be derived using mathematical methods.
- Establish the value of the resulting measured peak pressure ($\mathbf{p_{max}}$) from the point at which the mean pressure trace crosses the time of arrival axis. Note that this may differ slightly from a recorded instantaneous peak value.
- Establish the duration $\mathbf{t_+}$, of the mean pressure trace from the time of arrival to the point at which it crosses the ambient pressure axis. Note that the recorded trace may fluctuate below and above the line or may not cross the ambient line for a period significantly longer than $\mathbf{t_+}$.

- Calculate the value of the impulse, $\mathbf{i_+}$, i.e. the area under the trace, over the duration $\mathbf{t_+}$. This will be derivable from the digital record.
- Calculate the average values for peak reflected pressure and peak reflected specific impulse using the acceptable results as defined in Section 8.5: Test conditions and tolerances.

B.10 Verification

Verify that the average values of peak reflected pressure and peak reflected specific impulse derived above all comply with Section 5 of Part 1: Requirements and Classification.

National Protective Security Authority

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