Industrial risks and land use planning. Study of blast window resistance

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Abstract

Technological Risk Prevention Planning (PPRT) is a French tool for managing land-use planning near upper-tier SEVESO industrial facilities. Its purpose is to protect the population against industrial hazards. Risk limitation measures may include for example window reinforcement for new or existing blast risk exposed buildings. In order to better define technical guidelines for window reinforcement, INERIS developed an innovative experimental device. INERIS has studied window behaviour and has evaluated blast capacity of different kinds of glass panels (monolithic or insulated glasses with or without anti-explosion film, laminated glasses...), mobile frames or window locking or anchorage systems. Results show that all window components have to be considered to improve safety.

Keywords: PPRT, window, blast loading test

1. Introduction

Most of experimental studies consider blast loading with high intensity and short duration simulating detonating devices. Moreover they have mainly focused on the behaviour of monolithic glass panels (annealed or tempered). Weisman et al. [1] or Giltaire and al. [2], [3], [4] studied the response of monolithic or laminated glass subjected to blast shock wave within a short time (inferior to 10 ms). Coevert and al. [5] also studied security window film and insulating glass panel to high intensity blast load with a positive duration of approx. 1 ms to 10 ms.

In this paper, INERIS presented tests results of window subjected to a blast loading from accidental explosion characterized by a low intensity (20-50 mbar) and long duration (100 ms). These tests allowed to:

- Evaluate blast load capacity of different insulating glass panels
- Study the response of the whole window taking into account glass, frame, locking and anchorage system;
- Identify what the weak points are;

2. Experimental device

Tests are realised at a tunnel extremity. Window is fixed on rigid steel test frame. Steel and wood panels are placed on test frame around the window. It forms with tunnel walls a 25 m^3 box. An explosive charge is placed at the center of the box.

Figure 1: Experimental device outsideface

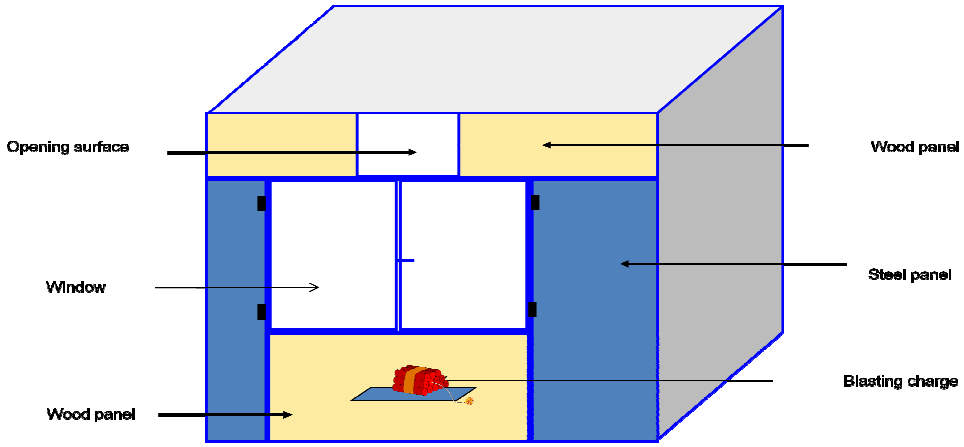


Figure 2: Schema of experimental device

Two pressure gauges record the blast load magnitude and time development impinging the window. One gauge is placed on the room floor. The other one is positioned on test frame near the window.

Figure 3: Blast pressure gauge

3. Tested windows

Tests allow to study:

- The blast capacity resistance of 1.20 m x 1.05 m different glass panels
  - Annealed insulating glass 4/16/4
  - Insulating glass 4/16/4 with daylight or wet-glazed security window film
  - Insulating glass fabricated with laminated glass 44.2/8/44.2

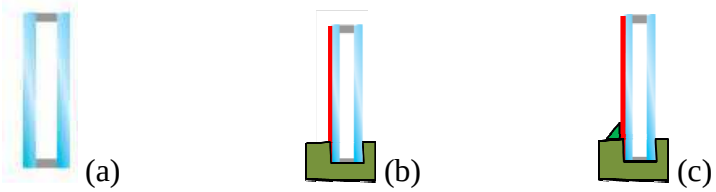
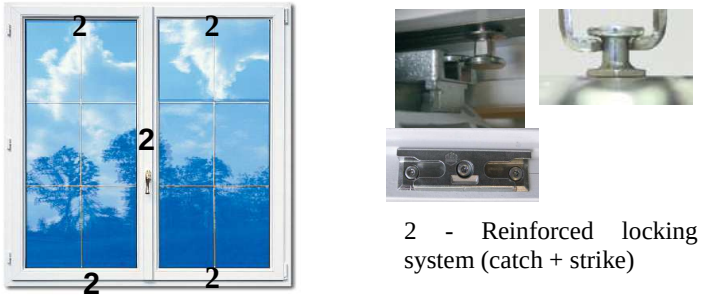


Figure 4: (a) Insulating glass, (b) insulating glass with daylight security window film, (c) insulating glass with wet-glazed security window film

- The behaviour of 1.40 m x 1.20 m French style inwards opening double window composed of
  - PVC frame and standard locking system
  - Wood frame and reinforced locking system

1 and 2 - – standard locking system (catch + strike)

Figure 5: Standard locking system window



2 - Reinforced locking system (catch + strike)

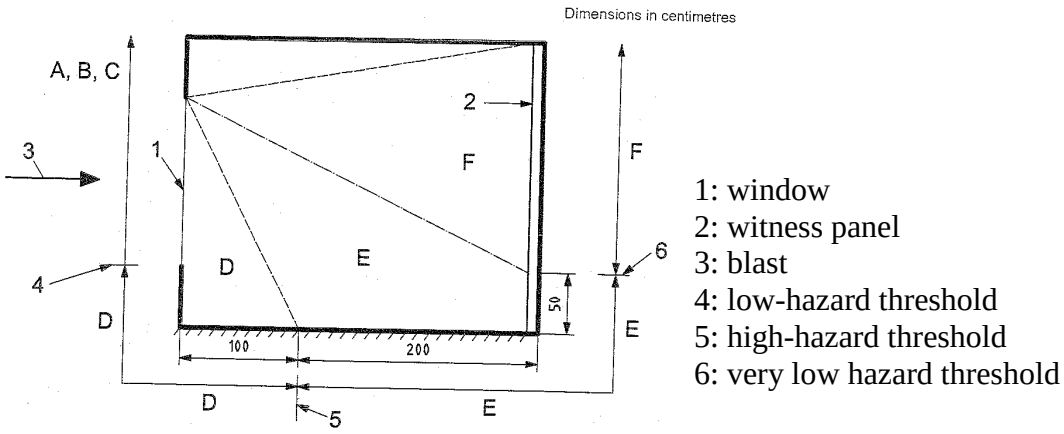
Figure 6: Reinforced locking system window

4. Results analysis

The evaluation of glazing performance is done in accordance with the evaluate hazard rating criteria in Table I [6]

Table I: Hazard rating criteria for tests

Hazard rating	Hazard ratio description
A	**No break**
B	**No Hazard**
C	**Minimal hazard**
D	**Very low Hazard**
E	**Low hazard**
F	**High hazard**



1: window
2: witness panel
3: blast
4: low-hazard threshold
5: high-hazard threshold
6: very low hazard threshold

Figure 7: Cross-section through witness aera

Glazing shall be considered as “blast-resistant” only if it achieves a “minimal hazard” rating C or safer.

A complete window is considered as “blast-resistant” only if:

- Glass achieves a “minimal hazard” rating C or safer.
- Window is still fixed to frame after the test
- Mobile frame are still closed after the test
- None piece of window is projected outside

5. Experimental results and discussion

5.1 Blast capacity resistance of glass panel

An initial series of [20-50 mbar] overpressure peak tests was performed to study the resistance of different glass panels. All panels were a 1.08 m x 0.60 m.
Tests results are given in Table II and Table III.

Table II: Glass panels subjected to blast load (part 1/2) – Results of blast tests

N°		1	2	3
Glass		4/16/4 Annealed Insulating glass		4/16/4 Annealed Insulating glass + Wet-glazed security window film
Dimensions of glass panel		h=1.08 m l= 0.60 m	h=1.08 m l= 0.60 m	h=1.08 m l= 0.60 m
Characteristic of blast wave	**Incident peakoverpressure (mbar)**	20-25	35-50	45-50
	Positive phase duration (ms)	> 500 ms	> 500 ms	> 500 ms
Hazard level		A	F	A

Table III: Glass panels subjected to blast load (part 2/2) – Results of blast tests

N°		3	4
Glass		4/16/4 Annealed Insulating glass + daylight security window film	44.2/8/44.2 Laminated Insulating glass (annealed glass)
Dimensions of glass panel		h=1.08 m l= 0.60 m	h=1.08 m l= 0.60 m
Characteristic of blast wave	**Incident peakoverpressure (mbar)**	50-55 mbar	65-70
	Positive phase duration (ms)	> 500 ms	> 500 ms
Hazard level		F	A

Table II shows that annealed insulating glass panels resist an incident of 20-25 mbar overpressure for hundreds of ms equivalent triangular duration. There was no damage to the glass. However increasing overpressure to 35-50 mbar causes the same glass to break (Figure 8) with most fragments projected up to 3 m (Figure 9).

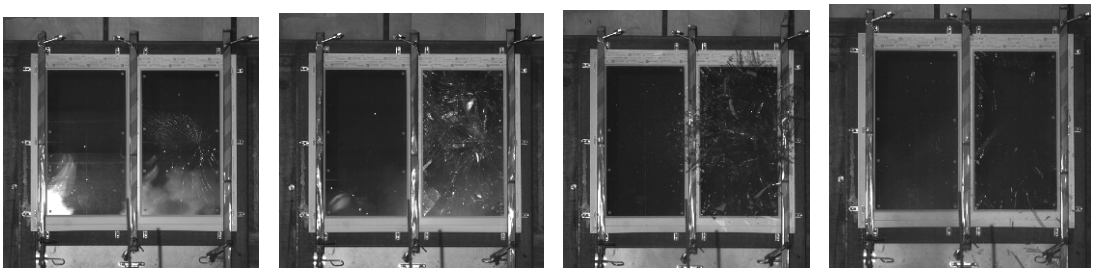


Figure 8: Insulating glass subjected to a blast wave

Figure 9: Fragments landed on the floor – zone 0-3 m

Insulating glass with a security film was also tested. This kind of film is applied internaly. Glass panel with a window film did not resist to a [20-50 mbar] blast load. During the blast The “Inner” pane was projected in one piece 2 meters from the window and the outer pane shuttered projecting pieces up to 3 m from the window. (Figure 10 and Figure 11).

On the other hand the use of wet-glazed window film does improve glass resistance. In that case, the glass does not shutter and the film stays on the frame. There is no glazing hazard (B rate).

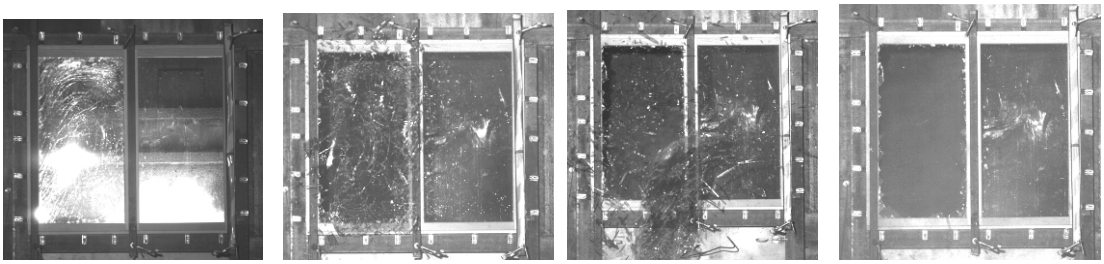


Figure 10: Annealed Insulating glass with daylight security window film subjected to blast wave

Figure 11: Annealed Insulating glass with daylight security window film – Post test

Another blast test also show that insulating glass made with laminated glass resists to a 50 mbar blast incident overpressure with a hundred milliseconds equivalent load duration.

Figure 12: Annealed Insulating glass with wet-glazed security window film – Post test

5.2 Blast capacity resistance of windows

A second test series studied the response of a French style inwards opening double window to a blast wave: resistance of the anchorage system, the fixed and mobile frame or locking system. All windows have a 1.25 m x 1.40 m^2 size. Test results are given in Table IV and Table V.

Table IV: Window subjected to blast load (part 1/2) – Results of blast tests

Dimensions of window		h=1.25 m x l= 1.40 m	
Opening window		French style inwards opening double window	
Anchorage system		Standard anchorage system : angle brackets clipped to the window and fixed to the structural framing	Reinforced anchorage system with angle brackets
Locking system		Standard locking system (catch + strike)	Standard locking system (catch + strike)
Frame		PVC	PVC
Glass panel		4/16/4	4/12/44.2
Blast wave	**Incident peakoverpressure (mbar)**	20-25	55-60
	Positive phase duration (ms)	> 500 ms	> 500 ms
Results		Deformation and rupture of anchorage system Rupture of frame Opening the window Projection of the window between 1 m and 2 m	Opening the window Rupture of mobile frame Projection of the window casement between 2 m and 3 m

Table V: Window subjected to blast load (part 2/2) – Results of blast tests

Dimensions of window		h=1.25 m x l= 1.40 m	
Opening window		French style inwards opening double window	
Anchorage system		Reinforced anchorage system with angle brackets	Reinforced anchorage system with angle brackets
Locking system		Standard locking system (catch + strike)	Reinforced locking system Individual closure of the openings
Frame		Wood	Wood
Glass panel		4/16/4	44.2-8-44.2
Blast wave	60-65	65-70	65-70
	> 500 ms	> 500 ms	> 500 ms
Results		Opening the window Rupture of mobile frame Projection of one of the opening at approximately 2 m	Mobile frames remain closed Glass panels intact

The inward opening window has a standard anchorage system constituted of 6 angle brackets (Figure 13) which are clipped to the window and screwed to the structural frame. Test results show that this system is not sufficient to resist a 20 mbar incident overpressure blast wave. Figure 14 shows deformation of angle brackets, an opening of window and a projection of the window between 1 m and 2 m.

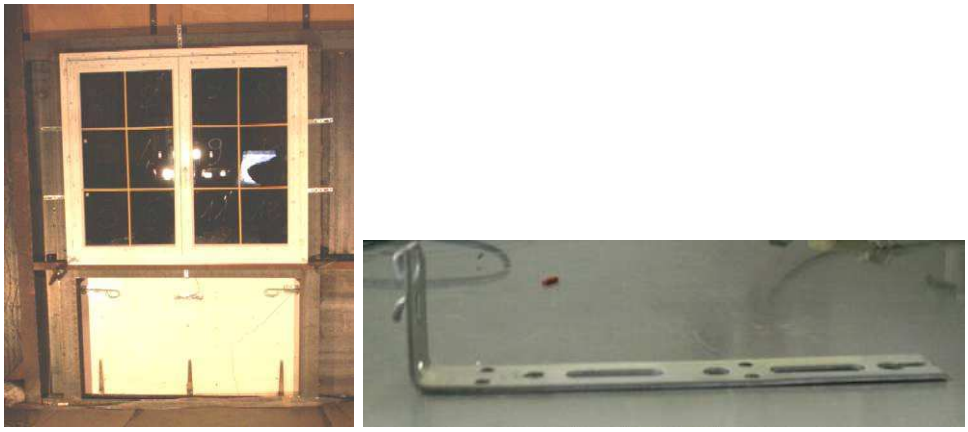


Figure 13: Window fixed with angle bracket (at left) – Angle bracket (at right)

Figure 14: Response of window to blast wave (at left) - Angle bracket after the test (at right)

For the second test the anchorage is reinforced in order to retain the window to the structural frame. Window is subjected to a 50 mbar incident overpressure. It does not resist either but the weak points have changed As shown in Figure 15, the mobile frames were broken and projected between 1 and 2 m. However fixed frame remained screwed to the building. The use of wood frame produces the same test results (Figure 15).

Figure 15: Projection of mofile frame of French style inwards opening window composed with PVC frame (at left) or wood frame (at right) and a common locking system (catch and strike)

Given the results of previous tests, a French opening window with a reinforced locking system illustrated in Figure 6 was tested. The window is composed of wood frame, laminated insulating glass and a reinforced anchorage sysem. It was subjected to a blast wave with a 50 mbar incident overpressure and an equivalent positive phase duration of hundreds milliseconds. Tests results showed that the configuration resists. The Glass panel was intact, The frame remained closed and attached to the frame (Figure 16).

Figure 16: French style inwards opening window with reinforced locking system, laminated glass and reinforced anchorage system subjected to blast wave – Photography after blast test

6. Conclusion

These experimental tests have produced new data on the response of windows subjected to a low incident overpressure and a long duration (hundreds of milliseconds) blast load.

Blast loading tests showed that a wet-glazed security window film improves the insulating glass panel resistance. Laminated insulating glass is also a good technical solution. However it is not sufficient to have a resistant glass panel. Reinforcing locking system and anchorage system are also recommended. All window elements have to be considered to improve safety.

Thanks to an experimental study and a theoretical analysis INERIS produced a practical guide [7] giving elements for improving the integrity of window subjected to a blast load**.** For instance, this guide gives recommendation on type and size of glass panel that can be used for various blast wave intensities and various blast wave types (deflagration or shock wave). It also indicates requirements for the locking system, the design and the number and position of the anchorage points.

Acknowledgments
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