

TECHNIQUES FOR CHARACTERIZING AND EVALUATING BLAST RESISTANT CLOSURE ASSEMBLIES

TECHNOLOGICAL FIELD

The present invention is generally in the field of blast resistant closure assemblies and relates to the design and evaluation of blast protected closure assemblies, such as used in glazed panels systems.

5 BACKGROUND

Energy absorbers (also referred herein as energy absorbing elements or energy absorbing anchors) can be used to connect a frame and closure (*e.g.*, glazed panel) assembly to a support structure provided in a wall opening (*e.g.*, jamb, lintel, doorpost) of a building or other such structures. The energy absorbers are designed to improve the
10 level of protection to occupants residing inside the building/structure in case the closure is exposed to blast waves *e.g.*, produced by an external explosion, by absorbing a substantial amount of the blast loading (*i.e.*, time dependent force, impulse, and pressure) applied over the closure. This closure assembly utilizing the energy absorbers is generally referred to herein as blast resistant closure assembly.

15 Buildings usually comprise a plurality of openings, the perimeter of each opening defining a support structure facing the opening that can be configured to receive the frame and closure assembly configured to substantially fill the space of the opening. The energy absorbing elements are usually metal plates having at least one base portion configured to connect to the support structure (*e.g.*, wall opening perimeter), at least one tongue
20 portion configured to connect to the frame holding the closure, and a plastically deformable portion connecting the at least one tongue portion to the at least one base portion. The energy absorbing elements can be inversely installed (*i.e.*, in an opposite direction), such that the at least one base portion is connected to the frame and the at least one tongue portion is connected to the support structure. The deforming portions of the
25 energy absorbing elements is configured to absorb some of the blast energy that hits the closure elements, by plastic deformation.

A proper design of the blast resistant closure assembly should prevent detachment of the closure element(s) (*e.g.*, glazed panel) from its support structure connecting it to

the wall of the building/structure, and substantially minimize propagation of fragmentation and blast waves into the building/structure, to thereby protect the occupants and reduce the risk of them being injured. It is known that the majority of bomb blasts injuries are from sharp flying (*e.g.*, glass) fragments travelling at high speeds inwardly into the building/structure. In glazed panels, for example, the closure comprises one or more laminated glass panels firmly held by the frame, such that though the glass panels are usually fractured by the blast waves, they remain attached to the frame and substantially prevent discharge of glass debris through the lamination layers, thereby reducing/preventing injuries.

10 Closure assemblies protection techniques known from the patent literature are briefly described below.

Korean Patent Publication No. 2011/0096346 discloses an explosion-pressure relieving device for windows and doors designed to increase effect of relieving explosion pressure by absorbing the explosion pressure in multi steps and increase the explosion pressure buffering effect. The relieving device is formed by an extendable flat member and is installed on the opening of a building's wall. The flat member comprises a pair of coupling holes, a first relieving unit and a second relieving unit. The coupling holes are formed on the upper and lower parts of the central line of the member. The first relieving unit is formed along a first length perpendicular to the central line and starts cutting from the central part if explosion pressure is applied. The cutting is done on both sides of the first length.

US Patent Publication No. 2009/038245 discloses an energy absorber for use in an opening of a wall of a building, the opening defined by a perimeter surface, the wall supporting a closure substantially filling the opening, the closure having respective edges which are substantially parallel to the perimeter surface of the opening. The energy absorber having a planar wall connecting portion, a planar closure connecting portion and a plastically deformable deforming surface therebetween. The connecting portions being substantially parallel to one another and, the deforming surface adapted to absorb, by plastic deformation, a force applied to the closure.

30 US Patent Publication No. 2008/086960 discloses a blast-resistant window assembly including a window opening and a window sized to fit within the window opening. The assembly further includes at least one anchor, which consists of a base plate connected to the window opening. The anchors have a tongue, which is connected to the

window and is fixed to the base plate at a shear region that is configured so that under force of a blast against the window, the tongue shears away from the base plate, thereby absorbing energy of the blast.

GENERAL DESCRIPTION

5 The present disclosure provides techniques for determining specifications of blast resistant closure assemblies *e.g.*, glazed panels (window), utilizing a plurality of energy absorbing elements (*e.g.*, such as described in US Patent Publication No. 2008/086960, of the same inventor hereof, the disclosure of which is incorporated herein by reference) to connect between a frame in which the closure is enclosed, and a support structure
10 provided in a wall opening (*e.g.*, jamb, lintel, doorpost) configured to receive and accommodate the blast resistant closure assembly.

 The term *closure element* as used herein refers to a member (infill *e.g.*, panes, laminated glass panels) configured to be installed in a frame, which is configured to fit in wall opening of a building/structure *e.g.*, door, window, or suchlike. The term *closure*
15 *assembly* as used herein refers to an assembly comprising a frame and one or more closure elements securely held by the frame for fitting into a wall opening of a building/structure.

 The blast resistant closure assembly disclosed herein comprises in some embodiments more than one closure element. The design of such blast resistant closure assembly generally includes the following steps:

20 **Step 1:**

 Blast response analysis/simulation (BRA *e.g.*, Single-Degree-of-Freedom\SDOF analysis, WINGARD or any other suitable software) conducted based on the geometrical dimensions of the closure elements, and some preliminary properties initially determined for the closure elements (*e.g.*, height, width, thickness, material type – elasticity, density,
25 plasticity), for determining velocities of each closure element of the closure assembly along the time axis, in response to predefined blast load conditions (pressure = P, and duration = T). The blast response analysis/simulation results are processed to determine a maximal velocity for each closure element of the blast resistant closure assembly in response to the predefined blast load conditions.

30 The determined maximal velocities are then used to calculate a peak kinetic energy of each closure element based on its mass. The total kinetic energy (E_{K_T}) transferred to the frame holding the closure elements under the predefined blast load

conditions is computed by summation of the calculated peak kinetic energies of the various closure elements of the blast protected closure assembly. An initial number (N) of energy absorbing elements to be used in the blast resistant closure assembly for a predefined required hazard level is then computed based on: (i) the determined total
5 kinetic energy (E_{KT}); and (ii) an optimized measure of kinetic energy load capability of a single energy absorbing element (E_{KE}) for a desired absorbance effect (*e.g.*, desired tear value - TV), as follow: $N = E_{KT} / E_{KE}$.

Step 2:

Optimal properties of the closure elements when assembled within a frame
10 equipped with energy absorbing elements are determined (*e.g.*, thickness, material type, *etc.*). Any SDOF (*e.g.*, WINGARD) analysis of the closure elements response when exposed to a blast loading assumes that the closure elements are supported by a fixed base. Where the closure elements are supported by energy absorbers their support is not fixed but actually moving with the energy absorbers plastic deformation progression.
15 Therefore, the dynamic shear load at the edges of the closure elements is reduced to the level of the dynamic load transfer of the energy absorbers. In other words, the dynamic load transferred from the energy absorbers to the supporting structure should be close to equal to the dynamic load at the edges of the closure elements.

The goal of this step is to identify closure elements characteristics/properties (*e.g.*,
20 thickness, material type, *etc.*) paired with a determined reduced blast load/impulse (I_R) that will satisfy the following conditions: (i) a predefined hazard level; and (ii) the dynamic load at the edges of the closure elements is greater than, or equal to, the dynamic load transfer of the energy absorbers. The response to the determined reduced blast load/impulse (I_R) can be calculated by at least one of the following blast response
25 analysis/simulation: to a reduced blast-pressure (P_R), and/or to a reduced blast-duration (T_R), with respect to the originally given blast loading used in the analysis/simulation of
Step 1.

The following conditions should be satisfied in the blast response analysis/simulation to response to the reduced blast-pressure (P_R) and/or blast-duration
30 (T_R):

- the closure assembly is installed with the number of energy absorbing elements determined in **Step 1** above;

- the average dynamic load transfer of a single energy absorbing element is determined experimentally (or by computer analysis/simulations);
- the edge shear load of the closure element is equal to, or greater than, the load transfer of the energy absorbing elements; and
- 5 • the blast response hazard rating determined by the blast response analysis/simulation (*e.g.*, WINGARD) satisfies a predefined hazard level.

This is done by iteratively analysing by blast response analysis/simulation of the blast resistant closure assembly with various different properties of the closure elements when exposed to a blast environment defined by either the reduced blast-pressure (P_R) and/or the reduced blast-duration (T_R). During this iterative analysis process closure elements properties yielding the predefined hazard level in response to the reduced blast load/impulse (I_R) and/or the reduced blast-duration (P_R and/or T_R) are recorded for further analysis. This analysis is used to identify closure elements (*e.g.*, glass makeup) with less demanding properties *e.g.*, thinner, lighter, lower costs, than those used in the fix base SDOF analysis (*e.g.*, Wingard) of **Step 1** above.

Step 3:

This is an optional verification step which may be carried out to determine whether the blast resistant closure assembly obtained in **Step 1**, together with the determined properties for the closure elements achieved in **Step 2**, satisfy conservation of momentum. The total blast momentum, or impulse (I_{BL}), of the blast resistant closure assembly is divided between the closure elements and the energy absorbing elements. Therefore, the total impulse I_{BL} should be equal to the momentum impacting the closure elements (I_{GL}) plus the momentum of the energy absorbing anchors (I_{EAA}). In this verification step the reduced blast impulse (I_R) achieved in **Step 2** (for the reduced pressure P_R , and/or the reduced time duration T_R , is used as the momentum impacting the closure elements (I_{GL}) to compute an average tear measure of the energy absorbing anchors in response to static load conditions. This verification is considered successful whenever the computed average tear measure is within acceptable values obtained experimentally (or by simulation) *i.e.*, the blast resistant closure assembly comprising the number of energy absorbing elements determined in **Step 1**, and the closure elements properties determined in **Step 2**, should satisfy the predefined hazard level.

One inventive aspect of the subject matter disclosed herein relates to a method of designing a blast resistant assembly having a frame, one or more closure elements secured

to the frame, and a plurality of energy absorbing elements distributed about a perimeter of the frame and configured to connect between the frame and a support structure. The method comprising in some embodiments determining an experimental blast load capability of a single energy absorbing element to predefined blast load conditions, 5
simulating response of the one or more closure elements with predetermined properties thereof, when connected directly to the support structure, to a blast event corresponding to the predefined blast load conditions, determining based on the simulated blast response velocities of the one or more closure elements during the simulated blast event, determining a number of the energy absorbing elements required for the blast resistant 10
closure assembly based on the determined experimental blast load capability and the determined velocities of the one or more closure elements, and verifying that the blast resistant closure assembly having the determined number of the energy absorbing elements satisfies a predefined hazard level condition.

Optionally, but in some embodiments preferably, the predetermined properties of 15
the closure elements comprise at least one of the following: height; width; thickness; elasticity; density; plasticity, of each closure one of the closure elements.

The method comprises in some embodiments processing the determined velocities for determining a peak kinetic energy of the closure assembly based thereon, and determining the number of the energy absorbing elements based on the peak kinetic 20
energy and the determined experimental blast load capability.

The method can comprising: (a) determining a blast impulse (I_{EAA}) acting on the plurality of energy absorbing elements under the predefined blast load conditions, and based thereon determining a residual blast load acting on the closure elements (I_{GL}) of the blast protected closure assembly, simulating response of the one or more closure elements 25
with the predetermined properties, when connected directly to the support structure, to a blast event capable of causing/applying the residual blast load (I_{GL}) to act on the closure elements, and verifying based on the simulated blast response that the blast resistant closure assembly satisfies the predefined hazard level condition.

In some possible embodiments the method comprises: (b) determining from the 30
simulated blast response to the blast event a blast load capable of causing the residual blast load (I_{GL}) and an edges blast impulse that of the closure elements edges inflect on the closure assembly frame (I_{CEDG}), and verifying the blast resistant closure assembly

satisfies the predefined hazard level based on the experimental blast impulse (I_{EAA}) and the edges blast impulse (I_{CEDG}).

The method can comprise: (c) simulating blast response of the one or more closure elements with their predetermined properties to one or more blast events, each one of the
5 one or more blast events associated with a respective blast pressure that is scaled down with respect to a blast pressure of the predefined blast load conditions, and verifying based on the simulated blast response that the one or more closure elements with their predetermined properties satisfy the following conditions: the predefined hazard level condition; and that an impulse acting on the edges of the closure elements is greater than,
10 or equal to, the blast impulse (I_{EAA}) acting on the plurality of energy absorbing elements.

Additionally, or alternatively, the method can comprise: (d) simulating blast response of the one or more closure elements with their predetermined properties to a one or more blast events, each one of the one or more blast events associated with a blast time duration that is scaled down with respect to a blast time duration defined by the predefined
15 blast load conditions, and verifying based on the simulated blast response that the one or more closure elements with their predetermined properties satisfy the following conditions: the predefined hazard level condition; and that impulse acting on the edges of the closure elements is greater than, or equal to, the blast impulse (I_{EAA}) acting on the plurality of energy absorbing elements.

20 The method can comprise selecting a reduced number of energy absorbing elements, and/or a new property (*e.g.*, reduced thickness, a reduced weight, and/or a different material type, of at least one of the closure elements), for the blast resistant closure assembly whenever the abovementioned verifying conditions are satisfied, and repeating the verification and steps (a) and/or (b) above for the reduced number of energy
25 absorbing elements and/or property. In some embodiments the method comprises changing at least one of the properties of the closure elements whenever the verifying conditions are not satisfied, and repeating the above method steps for the properties of the closure elements with the at least one changed property.

Optionally, but in some embodiments preferably, the method comprises utilizing
30 conservation of momentum analysis to verify that the blast resistant closure assembly employing the determined number of closure elements, or the reduced number of closure elements, the properties of the closure elements, or the properties of the closure elements with the at least one changed property, satisfies the predefined hazard level.

The method can comprise determining a static tear value (Δ_{tear}) and/or deformation property of the energy absorbing elements based on the the residual blast load (I_{GL}). A verification of the blast resistant assembly can comprise verifying that the determined static tear value (Δ_{tear}) is within predefined acceptable limits of the energy
5 absorbing elements *e.g.*, within a length of the element, or within acceptable limits determined by experiments and/or simulations.

In some embodiments the closure elements comprise glazed panels.

A further inventive aspect disclosed herein relates to a method of preparing a blast resistant closure assembly. The method comprising installing in a frame (*e.g.*, configured
10 to be received in a wall opening) one or more closure elements having the predetermined properties of the closure elements, or the newly determined property, or the at least one changed property, and attaching to the frame the determined (or the determined reduced) number of the energy absorbing elements.

Another inventive aspect of the subject matter disclosed herein relates to a blast
15 protected closure assembly designed and/or verified utilizing any of the above method steps, or as disclosed in the detailed description provided hereinbelow and/or the figures.

Yet another inventive aspect of the subject matter disclosed herein relates to a system for designing and verifying a blast resistant closure assembly. The system comprising an input device for receiving predetermined properties of one or more closure
20 elements of the blast resistant closure assembly, one or more processing units and memories configured and operable to receive and process the predetermined properties, and an analysis module configured and operable to carry out the steps of any of the methods described hereinabove above or hereinbelow based on the processed predetermined properties, to thereby determine one or more properties of the blast
25 resistant closure assembly and verify that it complies with a predefined hazard level condition.

Optionally, but in some embodiment preferably, the system comprises a plurality of sensor devices coupled to a test closure assembly and configured to generate measurement data indicative of time history blast forces and/or pressures acting over the
30 test closure assembly during a test blast event, and/or the time history of deflections and/or deformations of the closure assembly and/or of various components thereof. The one or more processing units can be configured to process the measurement data and determine based thereon at least one of the following: velocities of the closure elements,

optimized measure of kinetic energy load capability of a single energy absorbing element (EK_E), dynamic shear load at the edges of the closure elements during the test blast event, and/or a momentum over the energy absorbing anchors (I_{EAA}) during the test blast. The system can comprise an artificial intelligence module configured and operable to validate
5 and/or calibrate the analysis and/or simulations results of the analysis module.

Optionally, but in some embodiments preferably, the one or more processing units are configured and operable to generate a report comprising at least one of the following: the determined one or more properties of the blast resistant closure, the measurement data from the sensor devices, velocities of the closure elements, the determined optimized
10 measure of kinetic energy load capability of a single energy absorbing element (EK_E), the determined dynamic shear load at the edges of the closure elements during the test blast event, the momentum over the energy absorbing anchors (I_{EAA}) during the test blast, the analysis and/or simulations results, the analysis and/or simulations results as verified and/or calibrated by the artificial intelligence module, and/or the predetermined
15 properties of one or more closure elements.

A yet another inventive aspect disclosed herein relates to a report generated for a blast resistant assembly (*e.g.*, following any of the simulations, analysis, verification, procedures disclosed and illustrated herein), at least one of the following: the determined one or more properties of the blast resistant closure, the measurement data from the sensor
20 devices, velocities of the closure elements, the determined optimized measure of kinetic energy load capability of a single energy absorbing element (EK_E), the determined dynamic shear load at the edges of the closure elements during the test blast event, the momentum over the energy absorbing anchors (I_{EAA}) during the test blast, the analysis and/or simulations results, the analysis and/or simulations results as verified and/or
25 calibrated by the artificial intelligence module, and/or the predetermined properties of one or more closure elements.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with
30 reference to the accompanying drawings. Features shown in the drawings are meant to be illustrative of only some embodiments of the invention, unless otherwise implicitly

indicated. In the drawings like reference numerals are used to indicate corresponding parts, and in which:

Fig. 1 schematically illustrates energy absorbing elements according to some possible embodiments;

5 **Fig. 2** schematically illustrates a blast resistant closure assembly according to some possible embodiments;

Fig. 3 schematically illustrates the blast resistant closure assembly placed in a wall opening;

10 **Fig. 4** shows the energy absorbers of the blast resistant closure assembly after application of blast loads;

Fig. 5 is a flowchart schematically illustrating a process for design of blast resistant closure assemblies according to some possible embodiments;

Fig. 6 shows a graph plot of kinetic energy absorbed by energy absorbing elements of various tear levels (TVs);

15 **Fig. 7** shows experimental average load transfer plots of single-length and double length energy absorbing anchors;

Fig. 8 schematically illustrates a system for determining properties of blast resistant closure assemblies according to possible embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS

20 One or more specific and/or alternative embodiments of the present disclosure will be described below with reference to the drawings, which are to be considered in all aspects as illustrative only and not restrictive in any manner. It shall be apparent to one skilled in the art that these embodiments may be practiced without such specific details. In an effort to provide a concise description of these embodiments, not all features or
25 details of an actual implementation are described at length in the specification. Elements illustrated in the drawings are not necessarily to scale, or in correct proportional relationships, which are not critical. Emphasis instead being placed upon clearly illustrating the principles of the invention such that persons skilled in the art will be able to make and use the blast resistant closure assemblies and their design techniques, once
30 they understand the principles of the subject matter disclosed herein. This invention may be provided in other specific forms and embodiments without departing from the essential characteristics described herein.

The present application provides techniques for design of blast resistant closure assemblies configured to comply with a predefined hazard level (*e.g.*, as defined in ISO 16933 and/or the ASTM F2912 standards). The closure assembly design techniques generally comprise the following steps:

- 5 1. Utilizing blast response analysis schemes to determine a peak kinetic energy to be absorbed by the blast resistant closure assembly, and based thereon an initial number of energy absorbing elements required for the blast resistant closure assembly for the predefined hazard level;
2. Applying force equilibrium analysis schemes to the blast resistant closure
10 assembly utilizing the determined initial number of absorbing elements to determine properties of the closure elements (*e.g.*, thickness, material types, etc.) to satisfy the required predefined hazard level, and adjusting the number of absorbing elements based on the determined closure elements properties; and
3. (Optionally) utilizing conservation of momentum analysis to verify that the blast
15 resistant closure assembly employing the determined closure elements properties and the determined or adjusted number of energy absorbing elements satisfies the predefined hazard level.

For an overview of several example features, process stages, and principles of the invention, the blast resistant closure assemblies examples illustrated schematically and
20 diagrammatically in the figures are intended for glazed panels systems. These glazed panels systems are shown as one example implementation that demonstrates a number of features, processes, and principles used to provide blast resistant closure assemblies, but they are also useful for other applications and can be made in different variations (*e.g.*, using closure elements made from other material, such as, plastic, metal, ceramic, wood,
25 composite materials, etc.). Therefore, this description will proceed with reference to the shown examples, but with the understanding that the invention recited in the claims below can also be implemented in myriad other ways, once the principles are understood from the descriptions, explanations, and drawings herein. All such variations, as well as any other modifications apparent to one of ordinary skill in the art and useful in closure
30 applications may be suitably employed, and are intended to fall within the scope of this disclosure.

Fig. 1 schematically illustrates examples of energy absorbing elements (EAAs) **10a** and **10b** (collectively referred to herein as energy absorbing anchor or element **10**)

according to some possible embodiments. The energy absorbing element **10** in this specific and non-limiting example is a type of strap anchor configured to connect a glazed panel frame (**21** in **Fig. 2**) to a support structure (**30** in **Figs. 3** and **4**) provided in a wall of a building/structure. Once the glazed panel assembly (**20** in **Fig. 2**, also referred to
5 herein as blast resistant closure assembly) connected with the energy absorbing elements **10** is exposed to a blast shock wave, the energy absorbing elements **10** are partially, or entirely, torn, thereby absorbing at least some of the blast energy and acting as a fuse that limits the blast load transfer between the glazed panels assembly (**20**) and the support structure (**30**).

10 **Fig. 1** shows possible embodiments for a double-length energy absorbing element **10a** (e.g., having tearing lines length of about 100 to 200 mm), and a single-length energy absorbing element **10b** (e.g., having tearing lines length of about 60 to 100 mm). The double-length energy absorbing element is used in blast resistant closure assemblies designed for extreme intensity blast environments. These energy absorbing elements can
15 be fabricated, for example, from metallic and/or plastic materials, such as steel, for example, in form of straps having thickness in a range of 0.5 to 3 millimeters). Each of these energy absorbers **10** comprises at least one base portion (**11a**, **11b**) configured to securely attach (e.g., via screws holes **1a**, **1b**) to the support structure **30** provided in the wall of the building/structure, and at least one tongue portion (**12a**, **12b**) configured to
20 securely attach (e.g., via screws holes **2a**, **2b**) to the frame **21** of the closure assembly **20**. The at least one tongue portion (**12a**, **12b**) is connected to the at least one base portion (**11a**, **11b**) by a tearable strap (**15a**, **15b**) defined by two tear lines (**5a**, **5b** e.g., grooves) extending along a length of the energy absorbers **10**.

It is noted that the energy absorbers **10** can be similarly connected in an inverse
25 fashion, such that the at least one base portion (**11a**, **11b**) is connected to the frame (**21**) and the at least one tongue portion (**15a**, **15b**) is connected to the support structure (**30**).

Fig. 2 schematically illustrates a blast resistant closure assembly **20** according to some possible embodiments. The top side of the blast resistant closure assembly **20** is not shown (removed) in **Fig. 2**. In this specific and non-limiting example, the blast resistant
30 closure assembly **20** comprises two closure elements **22** (e.g., inboard and outboard laminated glass panels) securely held by a frame **21** e.g., made of plastic, steel, Aluminium. A number of energy absorbing elements **10** are securely attached by their tongue portions (**12a**, **12b**) to the sides of the frame **21**. In this non-limiting example four

energy absorbing elements **10** are securely attached to each side of the frame **21** *i.e.*, the blast resistant closure assembly **20** utilizes a total of $N=16$ energy absorbing elements (including the not shown energy absorbing elements of the top side).

Fig. 3 shows the blast resistant closure assembly **20** fitted into opening **25** formed in a wall **30** (also referred to herein as support structure) of a building/structure. The blast resistant closure assembly **20** is securely attached to the faces **25f** of the opening **25** by means of the base portions (**11a**, **11b**) of the energy absorbing elements **10**.

Fig. 4 shows the double-length energy absorbing elements **10a** after blast explosion forces are applied over the blast resistant closure assembly (**20**). As seen, each of the energy absorbing elements **10** is torn along its tearing lines (**5a**), thereby maintaining the blast resistant closure assembly (**20**) connected to the support structure **30**.

For glazed panels, for example, for a given blast loading, there are various different combinations of glass make-ups and arrangements of the energy absorbing elements **10** connecting the closure assembly to the window opening **25** perimeter that satisfies required predefined hazard level.

Fig. 5 is a flowchart illustrating a process **50** for design of a blast resistant closure assembly (**20**) according to some possible embodiments. Glazed panels systems designed by the process **50** were successfully tested by exposures to various intensity blast environments having peak pressures in the range of $P = 290$ to 500 psi, and impulse in the range of $I = 165$ to 720 psi $\times$ millisecond. The tested closure assemblies, and their respective specifications as obtained utilizing the process **50**, were analyzed by WINGARD (Window Glazing Analysis Response and Design by Applied Research Associates (ARA)) to predict velocities of the closure elements (inboard and outboard glasses) of such fixed base system designs when exposed to the full, tested or specified, blast load.

The process **50** starts in blast response analysis/simulation (**S2**), conducted based on the predefined blast load and an initial closure architecture (**S1** *e.g.*, defining geometrical dimensions of the closure elements, thickness, elasticity, plasticity, density and/or type of material of each closure element, and suchlike). The blast response analysis/simulation (**S2**) can be carried out by any suitable blast response analysis/simulation algorithm (*e.g.*, single-degree-of-freedom\SDOF analysis) or software (*e.g.*, WINGARD), to determine velocities of the closure elements along the

time axis under the defined blast conditions (**S1**). The analysis results are processed to determine maximal velocity (**S3** *e.g.*, using Dplot by Hydesoft Computing, LLC) of each closure element (**22**).

The determined maximal velocities (**S3**) are used to compute a peak kinetic energy for each closure element (**22** *e.g.*, fixed-base pane), which is used in step **S5** to determine the number of energy absorbing elements (N) required to provide the predefined hazard level. For example, if two closure elements (**22**) are used in the closure assembly (**20**) comprising an inboard element having a mass M_{ib} and a determined maximal velocity V_{ib} , and an outboard element having a mass M_{ob} and a determined maximal velocity V_{ob} , then the peak kinetic energies can be computed as follows:

$$EK_{ib} = \frac{1}{2} \cdot M_{ib} \cdot V_{ib}^2$$

$$EK_{ob} = \frac{1}{2} \cdot M_{ob} \cdot V_{ob}^2$$

The sum of the peak kinetic energy computed for each closure element (**22**) is defined as the total peak kinetic energy (EK_T) of the closure assembly:

$$EK_T = \frac{1}{2} \cdot (M_{ib} \cdot V_{ib}^2 + M_{ob} \cdot V_{ob}^2).$$

Next (**S5**), the total kinetic energy (EK_T) is used to compute an initial number (N) of energy absorbing elements for the closure assembly (**20**) based on a determined optimized measure of kinetic energy load capability of a single energy absorbing element (EK_E , an empirical value obtained through blast testing), for a desired absorbance effect as follows:

$$N = EK_T / EK_E.$$

The determined initial number (N) of energy absorbing elements (**10**) obtained this way is the number of energy absorbers required to absorb the total peak kinetic energy (EK_T) of the closure elements (**22**) when the blast resistant closure assembly (**20**) is exposed to the specified blast environment.

The energy absorbing element (**10**) is by far the weak link in the chain as demonstrated in static pull tests. Therefore, the design process **50** focuses on the performance of the energy absorbing elements. As will be described hereinbelow, proper design of the blast resistant closure assembly (**20**) and its energy absorbing elements (**10**) can be employed to reduce the requirements of the closure elements (*e.g.*, glass makeup, thickness), the moment of inertia of the frame (**21**), and the load transferred to the support structure (**30**).

For example, and without being limiting, in order to determine the optimized measure of kinetic energy load capability of a single energy absorbing element (EK_E also referred to herein as experimental blast load capability) for a desired absorbance effect, each blast-tested single-length energy absorbing element (**10b**) was given a tearing value (TV) between 0 to 5, based on the observed length of tear. A chart of the kinetic energy (EK) absorbed by the energy absorbing element versus its tearing value was drawn to determine a suitable regression line (*e.g.*, **60** in **Fig. 6**). For example, for the double-length energy absorbing elements tearing values between 0 to 6 were given.

In some embodiments, the required initial number (N) of energy absorbing elements used along a perimeter of a given opening (**25** *e.g.*, window) is determined using the TV for a single-length energy absorbing element, which is conservatively limited to 3.5, although closure assemblies (**20**) equipped with energy absorbing elements survived the predefined blast loading even when the TV is 4.5.

Using such optimized measure of kinetic energy load capability of a single energy absorbing element (EK_E) value to determine the number (N) of energy absorbing elements (**10**) required for the given blast conditions generally can guarantee that the frame (**21**) remains attached to the support structure (**30**) after absorbing the blast waves.

For glass panels, the integrated load transfer of the energy absorbing anchor/element ($I_{EAA} = \int (\text{average single EAA force}) \cdot dt$ *e.g.*, time history as measured by load cells in blast testing multiplied by the number of EAA integrated over time), and the integrated WINGARD dynamic glass edge shear reaction ($I_{GLEDG} = \int (\text{WINGARD dynamic glass edge shear reaction force}) \cdot dt$) can be used to predict the glass performance in blast resistant closure assemblies (**20**) equipped with the determined number of energy absorbing elements exposed to a known blast environment.

As demonstrated by static pull tests and blast testing (described below), the average resistance of a single energy absorbing element to the glass loading ($F_{EAAD} = \text{average single EAA force}$ *e.g.*, time history as measured by load cells in blast testing), does not change with blast intensity. A more intensive blast load will require using more energy absorbing elements ($N' > N$), which in turn will transfer a larger amount of force to the support structure ($N' \times F_{EAAD}$).

The WINGARD software is considered to be the industry standard glass performance and glass hazard level analysis tool, that is calibrated to a large number of arenas and shock tube tests. WINGARD is a fixed-base single degree of freedom analysis

tool, which assumes that the glass is supported by a rigid frame. Therefore, WINGARD cannot be used to determine the energy absorbing characteristics of the energy absorbing elements. In other words, and to satisfy conservation of momentum, WINGARD analysis considers that the applied blast impulse (I_{BL} , also referred to herein as baseline blast impulse) equals to the impulse acting over the closure elements (I_{GL}) *i.e.*, that $I_{BL} = I_{GL}$, and thus cannot actually analyze the blast response of the closure elements (22) when connected to the support structure (30) by the energy absorbing elements (10).

When a closure element (22) secured to a frame (21) equipped with the energy absorbing elements (10) is exposed to a blast shock wave, it starts to deflect. However, since the edges of the closure element (22) are supported in the blast resistant closure assembly by a frame (21) that moves in correspondence with the tearing of the energy absorbing elements, the relative deflection of the closure element (22), and therefore the glass hazard level, are respectively decreased. In this case the impulse (I_{BL}) applied by the blast load is divided between the closure element's (*e.g.*, glass) response, and the response of the energy absorbing element (10) at the perimeter of the frame (21).

As such, to satisfy conservation of momentum, the analysis of the blast resistant closure assembly (20) should actually also consider the impulse acting over the energy absorbing anchors/elements (I_{EAA}), as follows:

$$I_{BL} = I_{GL} + I_{EAA}.$$

This equation was demonstrated in past blast tests, where windows equipped with energy absorbing elements, achieved ASTM F2912 hazard levels of low hazard, or better, while the WINGARD software predicted a glass failure for the same conditions. It should be noted that in extreme low intensity blast environments, where any laminated glass will achieve “*very low hazard*”, or better, a situation may occur where $F_{EAAD} \geq F_{GLEDG}$ (where F_{GLEDG} = WINGARD's dynamic glass edge shear reaction force time history), in which the energy absorbing elements may not be activated at all *i.e.*, remain untorn.

The process (50) may proceed to iteratively (S6) conduct the blast response analysis to simulate the response of the blast resistant closure assembly (20) with the determined number (N) of the energy absorbing elements to reduced blast impulse conditions ($I_{GL}=I_R$) *i.e.*, reduction of the predefined blast load conditions (I_{BL}), $I_{GL}=I_R=I_{BL}-\Delta I$. For this purpose the blast pressure (P_{BL}), and/or time duration (T_{BL}), can be scaled down in each iteration to simulate the blast response of the blast resistant closure assembly (20) to blast impulses in the range $I_{GL}=I_{BL}$ to $I_{GL}=I_{BL}-I_{EAA}$ *i.e.*, the range

between the maximal blast impulse (I_{BL} , defined in **S1**) acting over the closure elements (22, *i.e.*, by neglecting the blast impulse I_{EAA} acting over the energy absorbing elements), and a blast impulse that substantially equals to the difference ($I_{BL}-I_{EAA}$) between the maximal blast impulse acting over the closure elements (22) and the blast impulse acting
5 over the energy absorbing elements (10).

In some embodiments this iterative blast response analysis (**S6**) is carried out for a range of scaled down blast pressure values $P_R=P_{BL}\cdot\beta$ (for $0<\beta<1$) to simulate blast response of the blast resistant closure assembly (20) to respective reduced blast pressure values (steps **p1** to **p3**), having the full time blast time duration (T_{BL}). Additionally, or
10 alternatively, this iterative blast response analysis (**S6**) is carried out for a range of scaled down blast time duration values $T_R=T_{BL}\cdot\alpha$ ($0<\alpha<1$) to simulate blast response of the blast resistant closure assembly (20) to respective reduced blast time duration values (steps **t1** to **t3**), and to the full blast pressure (P_{BL}).

For example, but without being limiting, Wingard analysis can be iteratively
15 performed to simulate/analyze the properties of the closure elements (22 *i.e.*, glass panels, dimensions) to the following conditions:

- (a) the full specified blast loading time-history (T_{BL}), with the scaled blast pressure ($P_R=P_{BL}\cdot\beta$); and/or
- (b) the full specified blast pressure (P_{BL}), with the scaled blast time duration ($T_R=T_{BL}\cdot\alpha$),
20 so as to simulate the blast response of the blast resistant closure assembly (20) to the reduced blast impulse (I_R), until the predefined hazard level is achieved (step **p2,t2**).

If it is determined, from the blast response analysis/simulation (**p1**), that the response of the blast resistant closure assembly (20) to the scaled blast pressure conditions (P_R) *i.e.*, for the reduced blast impulse (I_R), satisfies the required predefined hazard level
25 condition (**p2**), the time-history of the forces acting over the edges of the closure elements (F_{GLEDG}), as determined via the blast response analysis/simulation (**p1**), is processed to determine the blast impulse (I_{CEDG}) acting over edges of the closure elements (22) during the simulated blast event (*e.g.*, by time integration). The blast impulse (I_{CEDG}) acting over the edges of the closure elements (22) can be determined for all of the scaled blast
30 pressure values $P_R=P_{BL}\cdot\beta$ analysed/simulated in the range $0<\beta<1$, that satisfied the required hazard level condition (**p2**).

For example, but without being limiting, if the blast response analysis/simulation is carried out using Wingard simulations, the time-history of the forces acting over the

edges (F_{GLEDG}) of the closure elements (22), as generated by the Wingard software, is used to compute the blast impulse acting over edges of the closure elements (I_{CEDG}) *e.g.*, using the Dplot software to integrate F_{GLEDG} over time and compute I_{CEDG} .

Next, if it is determined that the predefined hazard level condition is satisfied (p2),
5 it is checked (p3) if the determined blast impulse (I_{CEDG}) acting over the edges of the closure elements (22) in the simulated scaled blast pressure is greater than, or equals to, the blast impulse (I_{EAA}) acting over the energy absorbing anchors/elements (10) of the blast resistant closure assembly (20) during the simulated blast event *i.e.*, $I_{CEDG}(I_{GL}=I_R) \geq I_{EAA}$. This condition (p3) can be checked for all of the reduced blast
10 pressure values $P_R = P_{BL} \cdot \beta$ analysed/simulated in the range $0 < \beta < 1$, that satisfied the required predefined hazard level condition (p2). In the Wingard analysis, for example, this comparison (p3) can be used to demonstrate that the energy absorbing elements (10) compliant glass reaction forces are smaller than, or equal to, the fixed base Wingard generated glass edge dynamic reaction forces.

15 If it is determined that the response of the blast resistant closure assembly (20) to the scaled blast pressure conditions (P_R) does not satisfy the predefined hazard level condition (p2), and/or that the $I_{CEDG}(I_{GL}=I_R) \geq I_{EAA}$ impulse condition (p3) is not satisfied, the blast response analysis/simulation (p1) is repeated for a further scaled down (*i.e.*, for smaller β value). If the $I_{CEDG}(I_{GL}=I_R) \geq I_{EAA}$ condition (S7) is not satisfied for any of the
20 reduced blast pressure values $P_R = P_{BL} \cdot \beta$ analysed/simulated in the range $0 < \beta < 1$, new properties (S8, *e.g.*, material types and/or thickness) are selected for closure elements (22), and the previous steps of the iterative blast response analysis (S6) are repeated for the newly selected closure elements properties and a new number (N) of energy absorbing elements determined (S5) for the new properties selected for the closure elements.

25 If the $I_{CEDG}(I_{GL}=I_R) \geq I_{EAA}$ condition (p3) is satisfied, another iterative blast response analysis/simulation (t1 to t3 *e.g.*, Wingard iterations) can be (but not necessarily) conducted for the blast resistant closure assembly (20) using the same closure parameters (*e.g.*, glass makeup and geometrical dimensions) and number (N) of the energy absorbing elements (10), and the predefined blast load conditions (I_{BL}), but with
30 a scaled down blast time duration ($T_R = T_{BL} \cdot \alpha$, for $0 < \alpha < 1$), until the required hazard level (t2) is achieved.

Next, it is checked if the required hazard level is satisfied (t2), and if so (t3) if the determined blast impulse (I_{CEDG}) acting over the edges of the closure elements (22) in the

simulated scaled blast time duration ($T_R = T_{BL} \cdot \alpha$) is greater than, or equals to, the blast impulse (I_{EAA}) acting over the energy absorbing elements **(10)** of the blast resistant closure assembly **(20)** during the simulated blast event *i.e.*, $I_{CEDG}(T_R = T_{BL} \cdot \alpha) \geq I_{EAA}$. This condition **(t3)** can be checked for all of the scaled blast time durations $T_R = T_{BL} \cdot \alpha$ analysed/simulated in the range $0 < \alpha < 1$, that satisfied the required hazard level condition **(t2)**.

If it is determined that the response of the blast resistant closure assembly **(20)** to the scaled blast time duration (T_R) does not satisfy the predefined hazard level condition **(t2)**, and/or that the $I_{CEDG}(I_{GL} = I_R) \geq I_{EAA}$ impulse condition **(t3)** is not satisfied, the blast response analysis/simulation **(t1)** is repeated for a further scaled down (*i.e.*, for smaller α value). If it is determined **(S7)** that the simulated closure elements properties cannot satisfy both conditions, $I_{CEDG}(P_R = P_{BL} \cdot \beta) \geq I_{EAA}$ and $I_{CEDG}(T_R = T_{BL} \cdot \alpha) \geq I_{EAA}$ for achieving the required hazard level, then new properties **(S8, e.g., material types and/or thickness, for example, to simulate a heavier and/or more substantial glass makeup)**, are selected for the closure elements **(22)**, and the previous steps **(S2-S6)** are repeated for the newly selected closure elements properties, and a new number (N) of energy absorbing elements determined **(S5)** for the new properties selected for the closure elements.

In some embodiments the additional iterative blast response analysis/simulation **(t1 to t3)** for the scaled down blast time duration ($T = T_{BL} \cdot \alpha$) is used as a precaution for guaranteeing that the predefined hazard level will be provided. Accordingly, in possible embodiments, the iterative blast response analysis **(S6)** can comprise only steps **p1 to p3** (*i.e.*, without steps **t1 to t3**). In yet other possible embodiments the iterative blast response analysis **(S6)** can comprise only steps **t1 to t3** (*i.e.*, without steps **p1 to p3**).

The iterative blast response analysis/simulations **(S2 to S8)** can be repeated until both conditions, $I_{CEDG}(P_R = P_{BL} \cdot \beta) \geq I_{EAA}$ and $I_{CEDG}(T_R = T_{BL} \cdot \alpha) \geq I_{EAA}$, are satisfied. When these conditions are met, the specifications (the properties of closure elements and number of energy absorbing elements) of the blast resistant closure assembly are recorded **(S9)** for further use and/or verification. The recordation **(S9)** of numerous blast resistant closures assemblies specifications may indicate that optimization of these specifications can be carried out. For example, and without being limiting, the process **50** may proceed (designated by dashed arrow lines) to optimize the specifications of the blast resistant closure assembly by repeating the iterative blast response analysis/simulations **(S6)** for a reduced number of energy absorbing elements and/or for reduced parameter defined by

the closure elements properties (**S10**, *e.g.*, N-1, and/or reduced thickness and/or mass of the closure elements).

In the process **50** of **Fig. 5** the properties of the closure elements (*e.g.*, glass makeup) is checked for the actual blast load that the energy absorbing elements will transfer when the closure elements (**22** *e.g.*, glazed panel) are exposed to the full specified blast load.

The test carried out using blast resistant glazed panels having Aluminum frames (**21**), which were installed within a rigid steel support frame by energy absorbing elements (**10**) attached along the full perimeter of the glazed panel. Load cells were installed in between the steel frame and the supporting structure (**30**), for measuring loads transferred by the rested glazed panels (**22**) to the supporting structure.

For each blast test, the force-time history measured by the load cells were divided (using Dplot) by the number (N) of energy absorbing elements (**10**) attached to the perimeter of the blast resistant glazed panel assembly, so the end result obtained is an average load time history (Newton Vs. msec) for a single energy absorbing element. Average load time histories, expressed as $F(t)$ [N, msec], determined from multiple tests were compiled together to create an average load transfer force-time history for a single energy absorbing element (F_{EAA}). **Fig. 7** shows average load transfer plots of single-length energy absorbing elements (**71**) and double-length energy absorbing elements (**72**), and of the time integrated load transfer of the single-length energy absorbing elements (**73**) and the time integrated load transfer of the double-length energy absorbing elements (**74**).

Conservation of momentum analysis is used in some embodiments to verify (**S11**) that the closure elements properties (*e.g.*, glass makeup and/or thickness) determined by the process **50** of **Fig. 5**, satisfies the conservation of momentum law: $I_{BL} = I_{GL} + I_{EAA}$. When simulating (*e.g.*, by Wingard) the scaled time-history load generated using either the reduced blast pressure ($P_R = P_{BL} \cdot \beta$, for $0 < \beta < 1$), or the reduced blast time duration ($T_{BL} \cdot \alpha$ for $0 < \alpha < 1$), as described with reference to **Fig. 5**, the tested reduced blast impulse I_R is fully resisted by the closure elements simulated with $I_{GL} = I_R$ *i.e.*, the blast impulse over the closure elements should be equal to the reduced blast load I_R tested in step **S6** and found to satisfy the checked validity conditions (**p2,p3** and/or **t2,t3**).

The kinetic energy absorbed by the energy absorbing elements (**10**) during the blast should equal to the work performed through the tearing of tearable strap (**15a, 15b**)

along the tearing lines/grooves (**5a, 5b**) i.e., $EK_{\text{tear}} = \frac{1}{2} \cdot M \cdot V^2 = F \cdot \Delta_{\text{tear}}$ [N·meter], and the blast impulse associated with the energy absorbing element response should equal $I_{\text{EAA}} = M \cdot V$, wherein M is the mass of the closure element (e.g., glazed panel), V is the velocity of the closure element, Δ_{tear} is the tear length of the energy absorbing element for a given blast loading at a given set of conditions, and F is the load required to tear the energy absorbing element (**10**) along Δ_{tear} at the given set of conditions. By rearranging these terms, the following expression is obtained: $I_{\text{EAA}} = (2 \cdot F \cdot \Delta_{\text{tear}} \cdot M)^{0.5}$.

In the verification step (**S11**) a tear level (Δ_{tear}) of the energy absorbing element (**10**) is computed for the closure properties determined for the predefined blast load and hazard level conditions under static force (F_{EAS}) required to maintain plastic deformation of the energy absorbing element (**10**). In a blast event the dynamic force F is not constant as in the static pull test, and it has a much complex force–displacement behavior. Therefore, a calibration factor (FAC) is introduced to match the empirical test results (see e.g., Biggs J. M. “*Introduction to Structural Dynamics*” McGraw-Hill, NY New York 1964), as follows:

$$\begin{aligned} F &= N \cdot F_{\text{EAS}} \cdot \text{FAC} \\ I_{\text{EAA}} &= (2 \cdot F \cdot M \cdot \Delta_{\text{tear}})^{0.5} = (2 \cdot N \cdot F_{\text{EAS}} \cdot \text{FAC} \cdot M \cdot \Delta_{\text{tear}})^{0.5} \\ I_{\text{EAA}} &= I_{\text{BL}} - I_{\text{GL}} \quad ; \quad I_{\text{GL}} = I_{\text{R}} \quad ; \quad I_{\text{EAA}} = I_{\text{BL}} - I_{\text{R}} \\ \Delta_{\text{tear}} &= (I_{\text{BL}} - I_{\text{R}})^2 / (2 \cdot N \cdot F_{\text{EAS}} \cdot \text{FAC} \cdot M) \end{aligned}$$

The tear level Δ_{tear} result obtained in the verification step (**S11**) should be within the limits set by the empirical data base e.g., based on experimental and/or simulation results.

Fig. 8 schematically illustrates a system **80** for determining properties of blast resistant closure assemblies according to possible embodiments. The system **80** comprises a control unit **82** configured to receive input data **81** (e.g., **S1** in **Fig. 5**), carry out blast response analysis/simulations and a blast resistant closure assembly design process (**50**) based on the received input data **81**, and generate outputs (e.g., report) **83** for presenting data indicative of the analysis/simulations results. For example, the input data **81** can include geometrical dimensions **81d** of the closure elements (**22**), the desired hazard level **81h**, blast load **81b**, and initial properties **81i** of the closure assembly (e.g., height, width, thickness, mass, material type, elasticity, plasticity, and/or density, of the closure elements). The output data **83** can include the number (N) **83n** of energy absorbing elements and the properties of the closure elements as determined by the design

process (50), the tear level **83v** calculated in the verification step (**S11**), and optionally some (or all) of the input data **81** received by the control unit **82**.

The control unit **82** comprises one or more processing units (**82u**) and memory units (**82m**), and an analysis module **82z** for carrying out a blast resistant closure assembly design process (50). The control unit **82** is configured in some embodiments to receive measurement data **88d** generated by a plurality of sensor devices **88** coupled to a test closure assembly **87** during a blast **89** configured to present a predefined blast load to be tested by the system **80**. The sensor devices **88** may utilize any sensing equipment suitable for measuring blast forces, pressures, velocities, accelerations, strains, deformations, etc.

10 In this specific and non-limiting example some sensor devices **88** are coupled to the closure elements **22**, and some sensor devices **88** are coupled to the energy absorbing elements **10**, of the test closure assembly **87**.

The control unit **82** can be configured to process the measurement data **88d** received from the sensor devices **88** and determine based thereon the velocities of the closure elements **22**, an optimized measure of kinetic energy load capability of a single energy absorbing element (E_{KE}), dynamic shear load at the edges of the closure elements during the test blast **89**, the momentum over the energy absorbing anchors (I_{EAA}) during the blast test **89**, and other data and/or parameters needed for the blast resistant closure assembly design process (50).

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20 The analysis module **82z** may be configured to carry out single-degree-of-freedom (SDOF), and/or multi-degree-of-freedom (MDOF), blast response analysis/simulations. In some embodiments an artificial intelligence (AI) module **82a** (e.g., utilizing machine/deep learning, neural networks, and suchlike) is used to validate and/or calibrate the SDOF/MDOS analysis/simulations results.

25 It should also be understood that throughout this disclosure, where a process or method is shown or described, the steps of the method may be performed in any order or simultaneously, unless it is clear from the context that one step depends on another being performed first.

Relative terms such as top, bottom, front, back, right, left, lower, upper, horizontal, vertical, above, below, up and down, as well as derivatives thereof (e.g., horizontally, downwardly, upwardly, etc.), and similar adjectives, should be construed to refer to the orientation as then described or as shown in the figures under discussion, not

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as any limitation to the orientations in which the apparatus can be used in actual applications.

As described hereinabove and shown in the associated figures, the present invention provides techniques for designing blast resistant closure assemblies and related
5 methods. While particular embodiments of the invention have been described, it will be understood, however, that the invention is not limited thereto, since modifications may be made by those skilled in the art, particularly in light of the foregoing teachings. As will be appreciated by the skilled person, the invention can be carried out in a great variety of ways, employing more than one technique from those described above, all without
10 exceeding the scope of the claims.

CLAIMS:

1. A method of designing a blast resistant closure assembly having a frame, one or more closure elements secured to said frame, and a plurality of tearable energy absorbing elements distributed about a perimeter of said frame and configured to connect between
5 said frame and a support structure, the method comprising:
 - determining or obtaining an experimental blast load capability measure of a single tearable energy absorbing element to predefined blast load conditions;
 - simulating response of said one or more closure elements with predetermined properties thereof, when connected directly to said support structure, to a blast event
10 corresponding to said predefined blast load conditions;
 - determining, based on the simulated blast event, velocities of said one or more closure elements during the simulated blast event;
 - determining a number of the tearable energy absorbing elements required for the blast resistant closure assembly based on the experimental blast load capability measure
15 and the determined velocities of said one or more closure elements; and
 - verifying that the blast resistant closure assembly having the determined number of the tearable energy absorbing elements satisfies a predefined hazard level condition.
2. The method of claim 1 wherein the predetermined properties of the closure
20 elements comprises at least one of the following: height; width; thickness; elasticity; density, plasticity, of each closure element.
3. The method of any one of the preceding claims comprising processing the determined velocities for determining a peak kinetic energy of said closure assembly
25 based thereon, and determining the number of the tearable energy absorbing elements based on said peak kinetic energy and the experimental blast load capability measure.
4. The method of any one of the preceding claims comprising:
 - determining a blast impulse (I_{EAA}) acting on the plurality of tearable energy
30 absorbing elements under the predefined blast load conditions, and based thereon determining a residual blast load acting on the closure elements (I_{GL}) of the blast resistant closure assembly;

simulating response of the one or more closure elements with predetermined properties, when connected directly to said support structure, to a blast event capable of causing said residual blast load (I_{GL}) to act on the closure elements; and

verifying based on the simulated blast response that the blast resistant closure
5 assembly satisfies the predefined hazard level condition.

5. The method of claim 4 comprising:

determining from the simulated blast response to the blast event a blast load capable of causing the residual blast load (I_{GL}) and an edges blast impulse that the closure
10 elements edges inflect on the closure assembly frame (I_{CEDG}); and

verifying the blast resistant closure assembly satisfies the predefined hazard level condition based on said experimental blast impulse (I_{EAA}) and said edges blast impulse (I_{CEDG}).

15 6. The method of claim 4 or 5 comprising: simulating blast response of the one or more closure elements with their predetermined properties to one or more blast events, each one of said one or more blast events associated with a respective blast pressure that is scaled down with respect to a blast pressure of the predefined blast load conditions; and verifying based on the simulated blast response that said one or more closure elements
20 with their predetermined properties satisfy the following conditions: the predefined hazard level condition; and that an impulse acting on edges of the closure elements is greater than, or equal to, the blast impulse (I_{EAA}) acting on the plurality of tearable energy absorbing elements.

25 7. The method of claim 6 comprising: simulating blast response of the one or more closure elements with their predetermined properties to said one or more blast events, each one of said one or more blast events associated with a blast time duration that is scaled down with respect to a blast time duration defined by the predefined blast load conditions; and verifying based on the simulated blast response that said one or more
30 closure elements with their predetermined properties satisfy the following conditions: the predefined hazard level condition; and that impulse acting on the edges of the closure elements is greater than, or equal to, the blast impulse (I_{EAA}) acting on the plurality of tearable energy absorbing elements.

8. The method of claims 6 or 7 comprising selecting a reduced number of tearable energy absorbing elements, and/or a new property, for the blast resistant closure assembly whenever verifying conditions are satisfied, and repeating the verification steps of claim 4 or 5 for the reduced number of tearable energy absorbing elements and/or said new
5 property.

9. The method of claim 8 wherein the new property comprises at least one of a reduced thickness of at least one of the closure elements, a reduced weight of at least one of the closure elements, and/or a different material type of at least one of the closure
10 elements.

10. The method of any one of claims 8 to 9 comprising changing at least one of the properties of the closure elements whenever the verifying conditions are not satisfied, and repeating claim 1 to 6 or 7 for the properties of the closure elements with the at least one
15 changed property.

11. The method of any one of the preceding claims comprising utilizing conservation of momentum analysis to verify that the blast resistant closure assembly employing a determined number of closure elements, or a reduced number of closure elements, the
20 properties of the closure elements, or the properties of the closure elements with the at least one changed property, satisfies the defined hazard level condition.

12. The method of any one of claims 4 to 11 comprising determining a static tear value (Δ_{tear}) and/or deformation property of the tearable energy absorbing elements based
25 on the residual blast load (I_{GL}), and verifying that the determined static tear value (Δ_{tear}) is within predefined acceptable limits of said tearable energy absorbing elements.

13. The method of any one of the preceding claims wherein the closure elements comprise glazed panels.
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14. A method for preparing a blast resistant closure assembly comprising:

installing one or more closure elements having the predetermined properties of claim 1 or 2, or the new property of claim 8, or the at least one changed property of claim 9, in a frame configured to be received in a wall opening; and

attaching to said frame the number of the tearable energy absorbing elements
5 determined in claim 1, 2, 3 or 8.

15. A blast resistant closure assembly comprising a frame articulable to a wall opening; one or more closure elements secured to said frame; and a number of tearable energy absorbing elements distributed about a perimeter of said frame and configured to
10 connect between said frame and said wall opening, said number of tearable energy absorbing elements configured according to an experimental blast load capability measure of a single one of said tearable energy absorbing elements to predefined blast load conditions and velocities of said one or more closure elements determined by simulation of response of said one or more closure elements to a blast event corresponding
15 to said predefined blast load conditions.

16. A system for designing and verifying a blast resistant closure assembly comprising:

an input device for receiving predetermined properties of one or more closure
20 elements of said blast resistant closure assembly;

one or more processing units and memories configured and operable to receive and process said predetermined properties; and

an analysis module configured and operable to carry out the method of any one of claims 1 to 11 based on processed predetermined properties to thereby determine one or
25 more properties of the blast resistant closure assembly and verify that said blast resistant closure assembly complies with the predefined hazard level condition.

17. The system of claim 16 comprising a plurality of sensor devices coupled to a test closure assembly and configured to generate measurement data indicative of blast forces
30 and/or pressures acting over said test closure assembly during a test blast event.

18. The system of claim 17 wherein the one or more processing units are configured to process the measurement data and determine based thereon at least one of the

following: velocities of the closure elements, optimized measure of kinetic energy load capability of a single tearable energy absorbing element (EK_E), dynamic shear load at the edges of the closure elements during the test blast event, and/or a momentum over energy absorbing anchors (I_{EAA}) during the test blast.

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19. The system of any one of claims 16 to 18 comprising an artificial intelligence module configured and operable to validate and/or calibrate analysis and/or simulations results of the analysis module.

10 **20.** The system of claim 19 wherein the one or more processing units are configured and operable to generate a report comprising at least one of the following: the determined one or more properties of the blast resistant closure, the measurement data from the sensor devices, velocities of the closure elements, the determined optimized measure of kinetic energy load capability of a single tearable energy absorbing element (EK_E), the
15 determined dynamic shear load at the edges of the closure elements during the test blast event, the momentum over the energy absorbing anchors (I_{EAA}) during the test blast, the analysis and/or simulations results, the analysis and/or simulations results as verified and/or calibrated by the artificial intelligence module, and/or the predetermined properties of one or more closure elements.

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