An assessment of architecturally appealing, semi-open shock mitigation devices

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Abstract

Purpose – Limitations in space and city planning constraints have led to the search for alternative shock mitigation devices that are architecturally appealing. The purpose of this paper is to consider a compromise solution which consists of partially open, thick, bending-resistant shapes made of acrylic material that may be Kevlar- or steel-reinforced. Seven different configurations were analyzed numerically.

Design/methodology/approach – For the flow solver, the FEM-FCT scheme as implemented in FEFLO is used. The flowfields are initialized from the output of highly detailed 1-D (spherically symmetric) runs. Peak pressure and impulse are stored and compared. In total, seven different configurations were analyzed numerically.

Findings – It is found that for some of these, the maximum pressure is comparable to usual, closed walls, and the maximum impulse approximately 50 percent higher. This would indicate that such designs offer a blast mitigation device eminently suitable for built-up city environments.

Research limitations/implications – Future work will consider fully coupled fluid-structure runs for the more appealing designs, in order to assess whether such devices can be manufactured from commonly available materials such as acrylics or other poly-carbonates.

Practical implications – This would indicate that such designs offer a blast mitigation device eminently suitable for built-up city environments.

Originality/value – This is the first time such a semi-open blastwall approach has been tried and analyzed.

Keywords Design, Architecture, Hazard prevention in buildings, Blast mitigation, Shock-structure interaction, CFD, Finite elements, Numerical methods

Paper type Research paper

1. Introduction

Explosions remain the most frequently used form of terror attack. They represent a low-tech, cheap, abundantly available resource that produces the desired destructive, psychological (mainly fear and rage), public-opinion (monopolization of news), economic (disruption of travel, commerce, investment and consumption) and political (destabilization) effects. Traditional ways to mitigate blast effects include the establishment of safe distance perimeters, reinforcement of windows and walls, as well as the construction of walls and other protective structures. For example, the Unified Facilities Criteria (2002) which became effective in October of 2005 mandate the following minimum stand-off distances for buildings: 45 m from a controlled perimeter, 25 m from an access-controlled parking lot and 10 m between buildings.

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Achieving such stand-off distances may not be possible in existing city environments. After all, 45 m implies half a city block, a space no city planner would consider to lay waste for a potential blast scenario. Walls see, e.g. Borgers (2010 and the references cited therein for a recent review), the next logical blast mitigation device, typically affect negatively the urban landscape, and may therefore not be acceptable to city planners.

This has led to the quest for alternative shock mitigation devices that are architecturally appealing. The main criteria considered were the following:

- Inobtrusiveness to pedestrians: the device should not affect the movement of pedestrians in the vicinity of buildings; and
- Visual appeal: the device should not affect the visual landscape of buildings; this implies that the devices considered must be either completely or semi-transparent.

The compromise solution considered here consists of partially open, thick, bending-resistant shapes made of acrylic material that may be Kevlar- or steel-reinforced.

2. Open, transparent walls

The key concept is best illustrated by considering the situation shown in Figures 1-3. In cases such as this, walls lead to considerable blast mitigation. In order not to negatively affect the urban landscape, and to allow pedestrians to transit freely, a number of semi-open walls were devised and tested. The “footprint” of these is shown in Figure 3. Each of these semi-open walls allows pedestrians to transit through them.

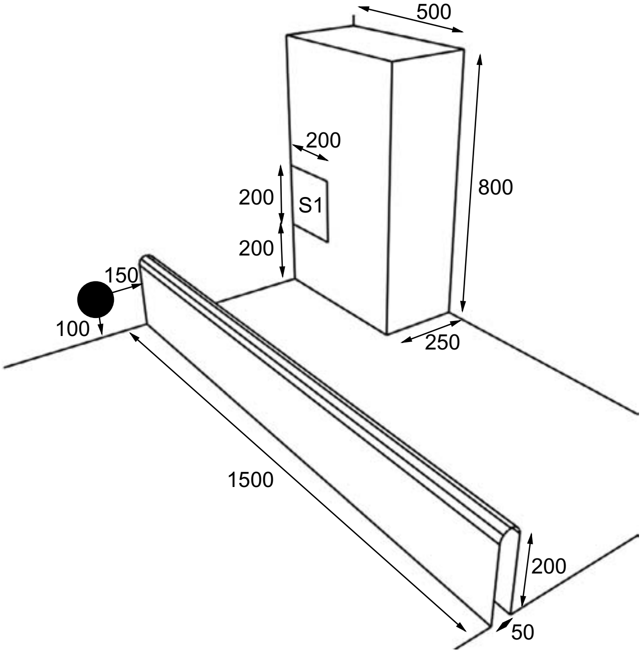

Figure 1.
Base configuration

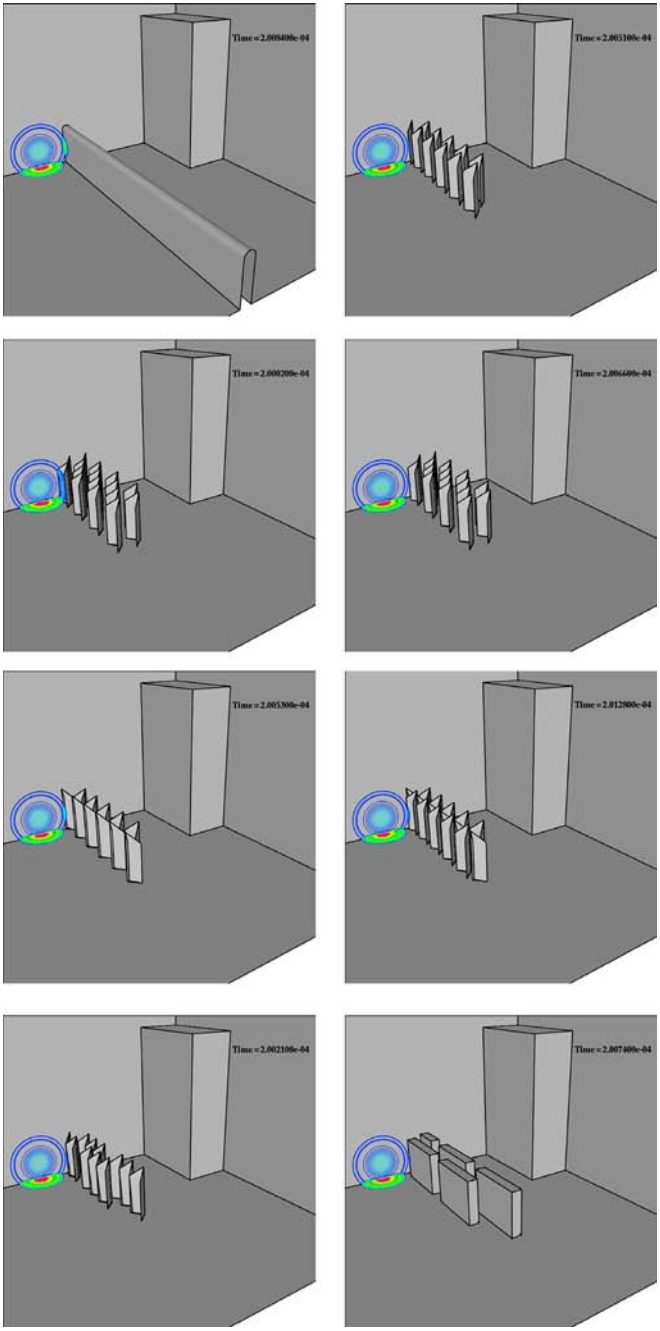

Figure 2.
Alternatives considered

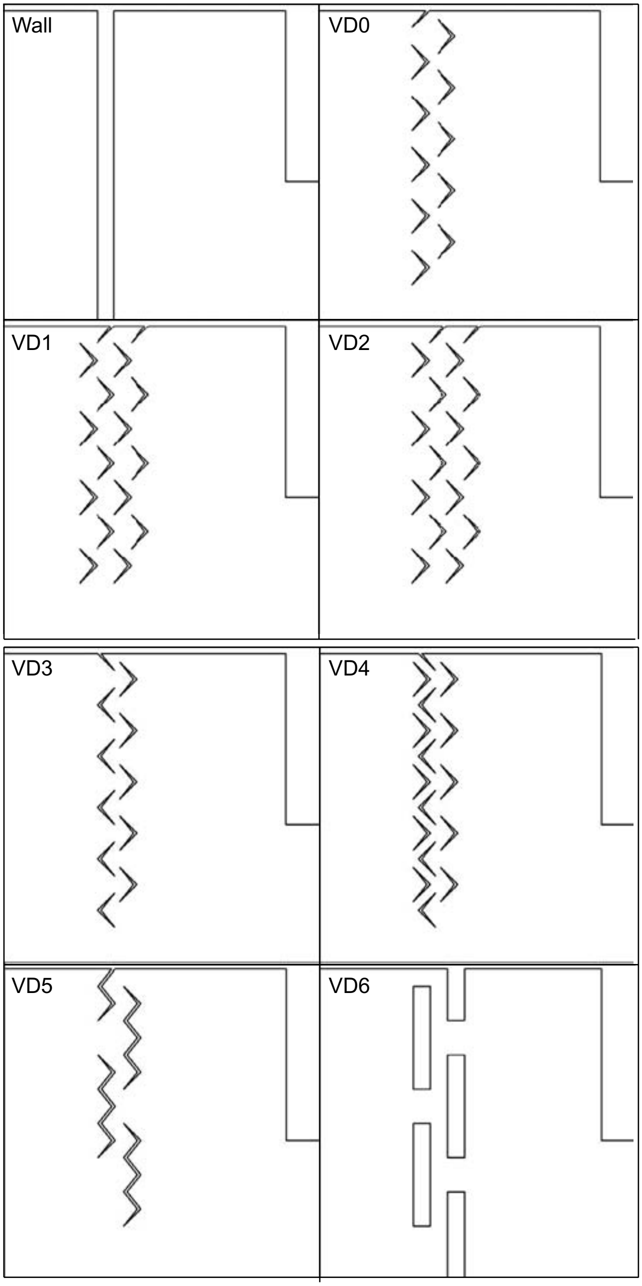

Figure 3.
Footprint of alternatives considered

Note that most of these are based on L-shaped ("corrugated") elements. Such shapes offer a higher bending stiffness, and at the same time lead to complex shock diffraction and inner vortex formation, both of which were shown to be highly effective damping mechanisms (Baum and Löhner, 1992). However, a single row of these does not offer any significant load reduction on the building: if the blast origin is placed directly in front of the opening, the blast will hit the building unimpeded. Therefore, it is necessary to use two or three rows in order to achieve a complete "visual blocking" of the potential target from the blast origin. The number of potential configurations and geometries is clearly limitless. The object of the present study was to take a few plausible shapes and see what blast attenuation could be obtained with them.

3. Methodology

In order to compare the relative merit of the different configurations, the model problem shown in Figure 1 was studied. Thus, a number of blast-structure calculations were required. Any blast-structure simulation proceeds through the following stages:

1. pre-processing;
2. grid generation;
3. flow solver; and
4. post-processing.

In the pre-processing phase, the data and boundary conditions are acquired and defined, the desired mesh size is specified and all run-time files are prepared. For the applications shown here, these tasks were carried out with FECAD (Löhner *et al.*, 2001). The computational domain was then filled with tetrahedral elements of specified size by using FEGEN, which implements the advancing front technique (Löhner and Parikh, 1988; Löhner, 1996). The flow was assumed to be compressible, inviscid and non-conducting. This assumption is perfectly reasonable given the small timescales involved and the inviscid nature of the pressure loads being computed. For the flow solver, the FEM-FCT scheme (Löhner *et al.*, 1987) as implemented in FEFLO (Löhner *et al.*, 2001, 2002) is used. The flowfields are initialized from either user-specified tables or the output of 1D, 2D/axisymmetric or fine 3D results. For more than a decade, FEFLO has been validated and in constant use for the class of applications being considered here (Baum *et al.*, 1993, 1998, 1999, 2003, 2006; Löhner *et al.*, 2004, 2008; Rice *et al.*, 2008; Löhner and Baum, 2009; Togashi *et al.*, 2009). Post-processing is carried out using FEPOST and ZFEM (Löhner *et al.*, 1989; Cebral and Löhner, 1998), as well as several x/y plotting tools such as gnuplot. All the pre- and post-processing, as well as any run requiring less than 48 Mtet elements are run on the PC, allowing for full integration under a single graphical user interface.

4. Calculations performed

In order to compare the relative merit of the different configurations, the model problem shown in Figure 1 was studied. Load (100 kg of TNT) and blast origin (HOB 100 cm above ground, 150 cm from wall) were kept the same for all cases. A grid refinement study was carried out for the first case. Once a sufficiently converged result was achieved, the same mesh-size parameters were used for all subsequent geometries. This resulted in grids of approximately 24 Mtets. For the wall case, the resulting surface mesh is shown in Figure 4. Note that in the direction away from the building the mesh size increases rapidly in order not to waste resources where none are required. The initialization of the 3D flowfield was carried out by interpolating the results from a very detailed 1D (spherical symmetry) calculation. A typical run is shown in Figure 5. A comparison of the (point) loads and impulse seen by window S1 (Figure 1) and a comparison of the maximum pressure and maximum impulse seen by the front face of the building are shown in Figures 6-8. The configuration VD0 (L-elements) was tested first. Even though it reduced loads as compared to no wall, one can see that the peak pressures and impulses (typical measures used by structural engineers to assess potential damage) are much higher than those of the pure wall case. The reason is that there is room for the shock wave to pass basically unimpeded through this semi-open wall (at 45°). Based on these results, all other configurations were designed so that a complete "visual blocking" was achieved. Configurations VD1 and VD2 are the same, except that VD2 starts at the same place as the usual wall. This was done so that all configurations could be compared fairly. As expected, VD1, which is closer to the blast origin, leads to lower peak pressures and impulses than VD2, although both configurations offer a much higher degree of blast mitigation than VD0. VD3 represented an attempt to use only two rows of elements instead of three. Even though better than VD0, this configuration is not as good as VD2. Adding another row in front of it leads to configuration VD4, which is comparable to VD2. Based on these results, alternative geometries were explored. The next logical configuration was a combination of basic L-elements, which is denoted as VD5: two rows of three joined L-elements. This configuration had remarkably good blast mitigation properties: both the peak pressures and impulses are lower than VD0-VD4.

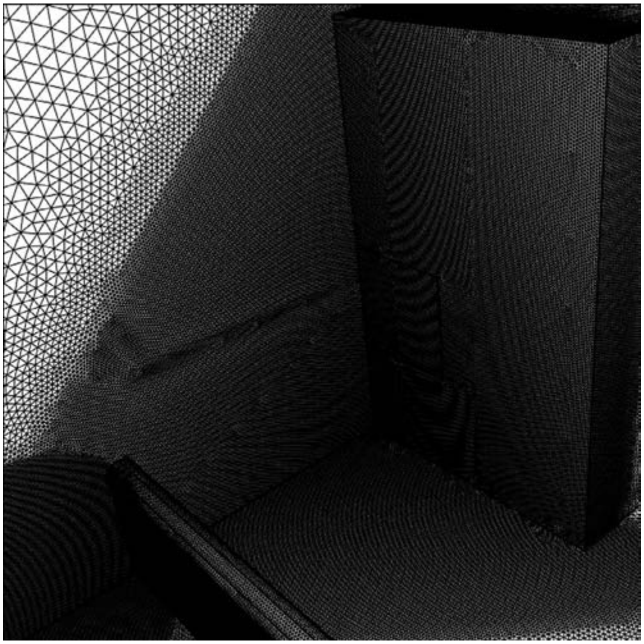

Figure 4.
Surface mesh for typical run

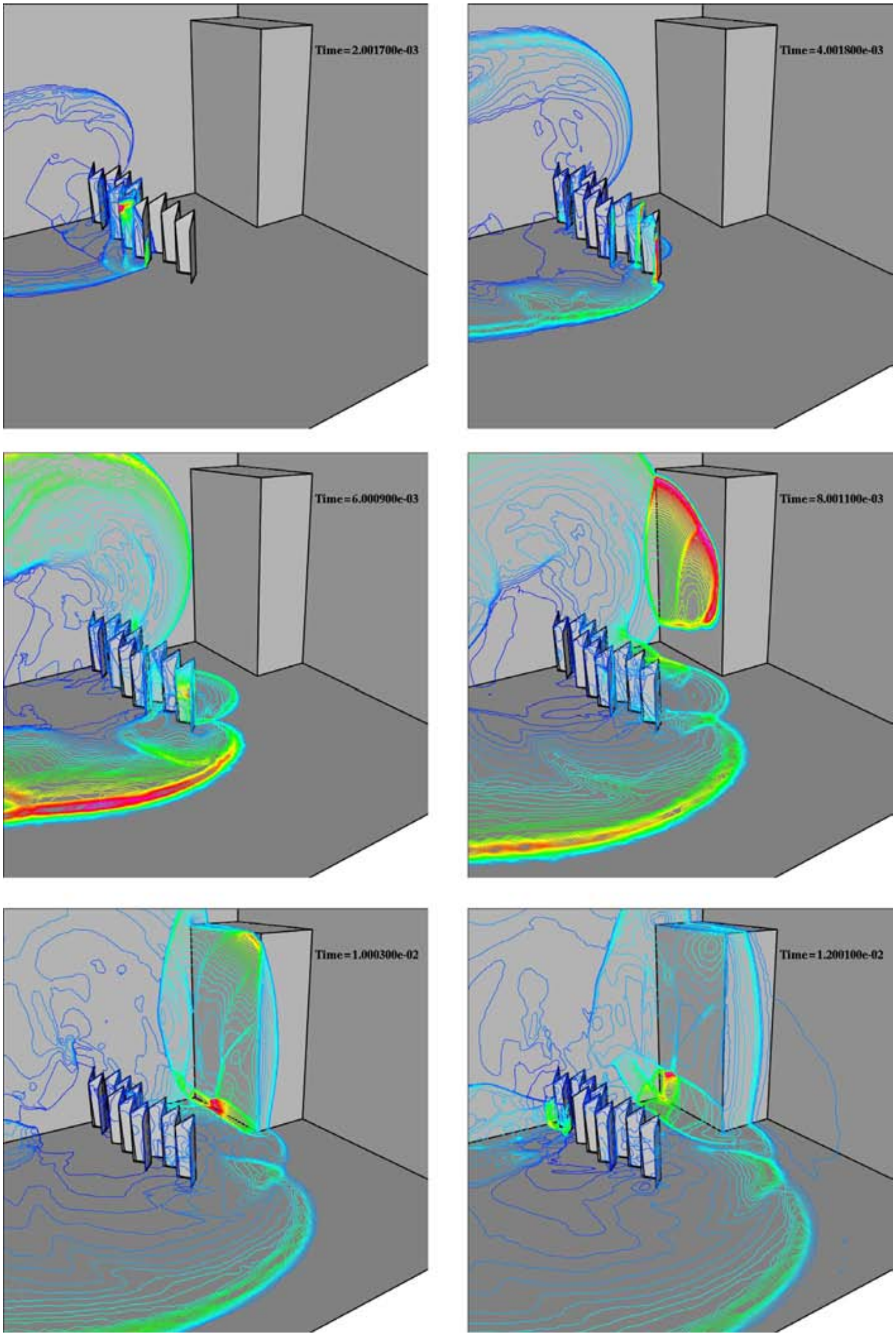

Figure 5.
Typical run: pressures on surfaces

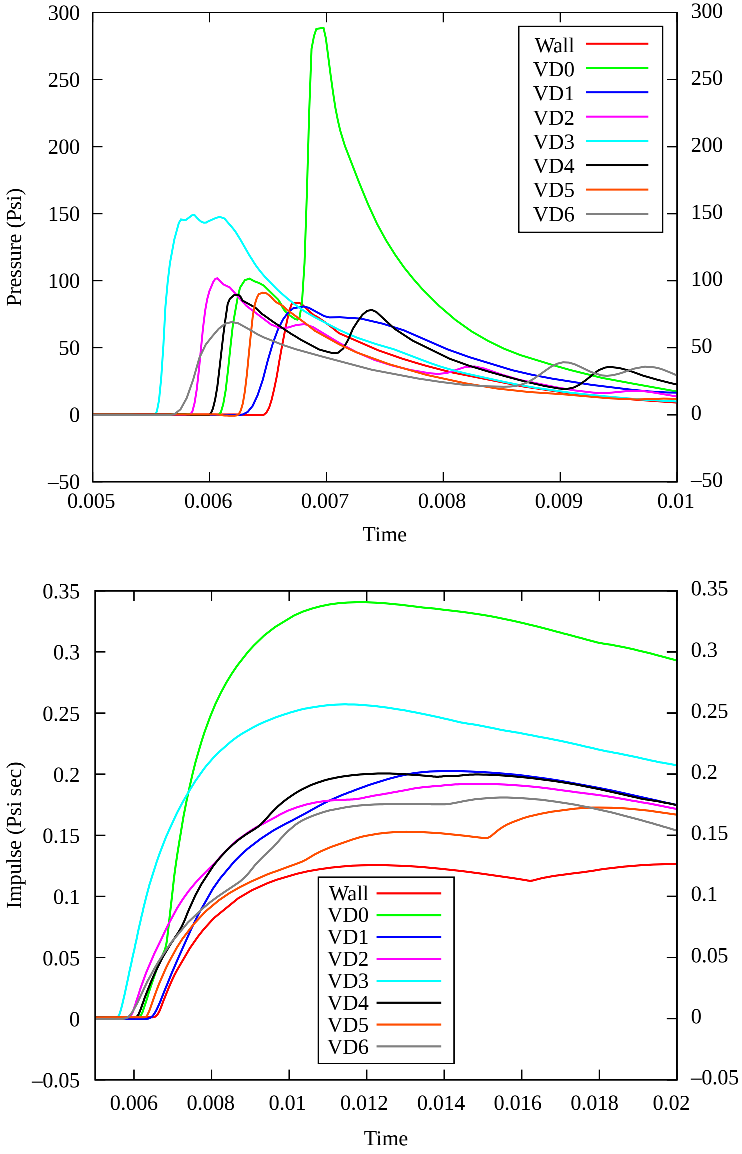

Figure 6.
Comparison of pressure and impulse time histories

Encouraged by these findings, and in order to achieve a better overall comparison, the original wall was also broken up into similar elements (VD6). This semi-open wall is not as good as VD5 (as may bee seen from both the point loads of the window S1 (Figure 6) and the overall loads on the building (Figures 7 and 8), but it is still more effective than VD0-VD4. In summary, the best configuration found is VD5: the peak pressures are comparable and the maximum impulses are at most 50 percent higher than those of the closed wall.

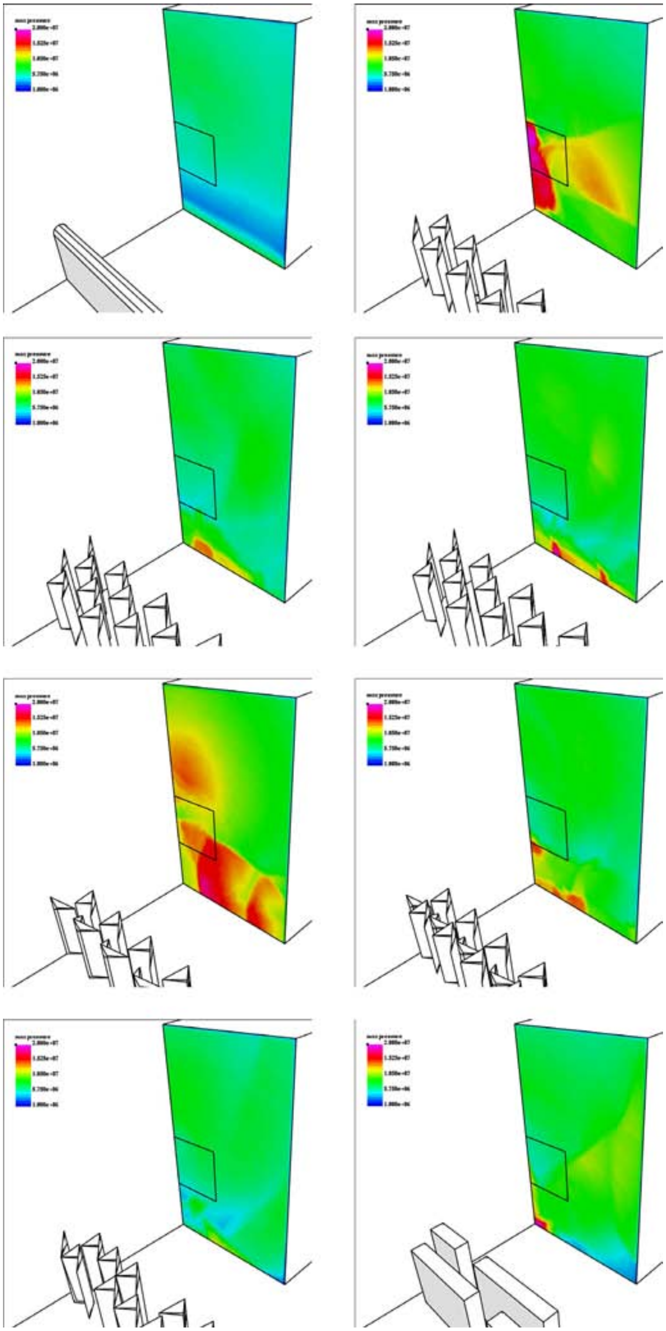

Figure 7.
Maximum pressure on wall (1.0×10^6: 2.0×10^7 dynes)

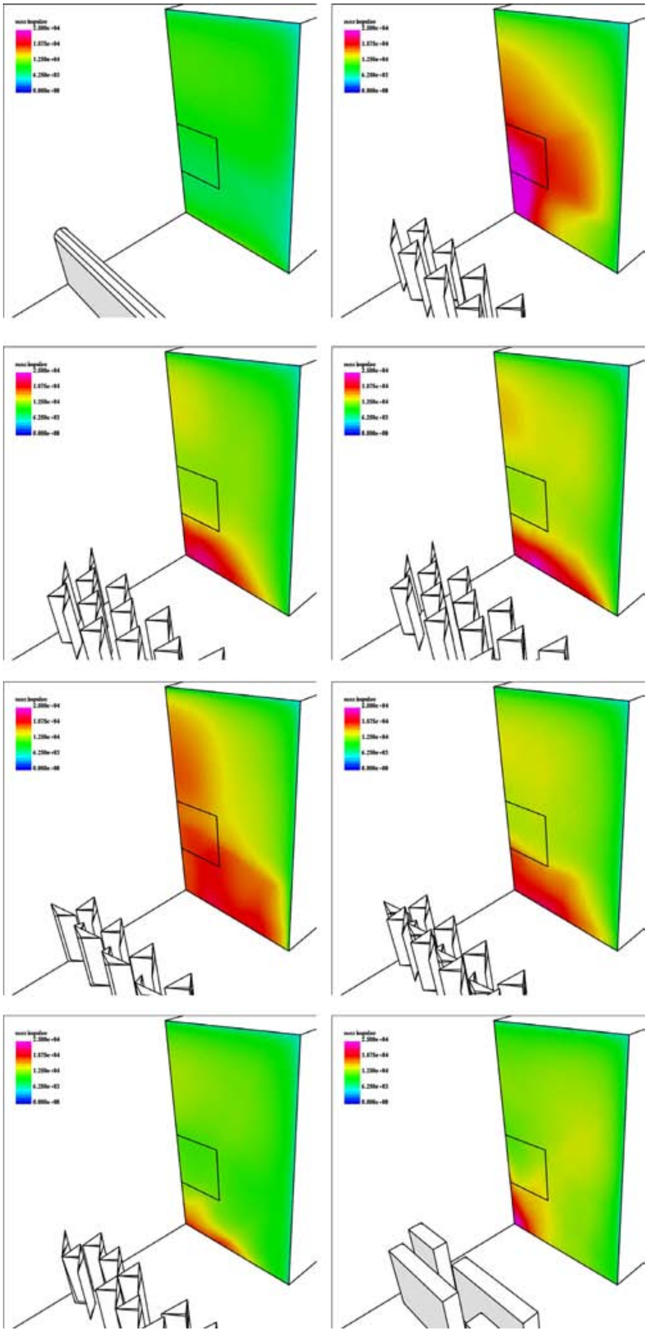

Figure 8.
Maximum impulse on wall
(0.0: 2.4×10^4 dynes sec)

5. Conclusions

The blast mitigation potential of architecturally appealing alternatives to blastwalls has been investigated numerically. Seven different designs were compared. It was found that for some of these, the maximum pressure is comparable to usual, closed blastwalls, and the maximum impulse approximately 50 percent higher for the blast stand-off distance and load considered. This indicates that such designs have the potential to offer an alternative blast mitigation device that city planners may find acceptable.

The number of potential configurations and geometries for semi-transparent walls is clearly limitless. The object of the present study was simply to take a few plausible shapes and see what blast attenuation could be obtained with them. The intent is to follow up the present work with detailed design studies for the most promising candidates. This will involve a large parameter space (load, stand-off, geometry) and hence many calculations, but should shed a clearer light on the effects of the open area coverage fraction, the width of free spaces, the distance and number of rows, etc.

Future work will also consider fully coupled fluid-structure runs for the final designs, in order to assess whether such devices can be manufactured from commonly available materials such as acrylics or other poly-carbonates (Evonik Röhm GmbH, 2010).

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