Numerical assessment of a blast-protective steel gate with a new damping system

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Abstract

Blast resistant gates are essential for sensitive infrastructure, such as embassies, ministries or parliaments. Lightweight gates equipped with 'energy absorbing systems' have better operational performance than the traditional costly and bulky design. Auxetic panels have not yet been used as potential damping systems in the supporting frame of blast resistant gates. Consequently, this numerical study tries to investigate if auxetic panels could probably eliminate permanent plastic deformations and maintain the gate operable after high blast pressure of 6.6 MPa, from 100 kg TNT at 5 m stand-off distance. Blast-induced response of a 3000x4500 mm steel gate was assessed, with and without the proposed energy dissipaters, using Abaqus/Explicit solver. Results showed that auxetic dampers can be a promising solution to maintain blast resistant gates operable after a blast event.

Keywords: damping systems, blast resistant gates, numerical simulation

1. Introduction

Unexpected explosions, from accidents or terrorist actions, have become a major public security threat that is wide spread around the world [1]. Perimeter walls are one of the options to protect sensitive infrastructure. However, they require secured gate for the vehicles or occupants to access the premises. Lightweight doors/gates equipped with 'energy absorbing systems' are more favoured than the traditional bulky design, that leads to poor operational performance and high cost [2]. Cellular materials; such as metal foams, honeycomb and auxetics; are among the preferred options to absorb blast energy through plastic deformation. Recently, auxetic panels attracted more attention due to their energy absorption potential [3]. A research by Hou, et al. [4] reveals that re-entrant topology, where the auxetic effect of negative Poisson's ratio appears, sustained larger impact strength than hexagon honeycomb of the same size and material. Auxetic panels have not yet been used as potential damping systems in the supporting frame of blast resistant gates. Consequently, this numerical study tries to investigate if auxetic panels could probably eliminate permanent plastic deformations and maintain the gate operable after a relatively high blast pressure.

2. Case Study

The gate is situated in an urban area with minimum permissible stand-off distance of 5 m. To achieve this clearance, barriers should be provided to prevent near field explosion scenarios (Figure 1). In return, protection from direct shock, heat or debris impact can be achieved. The entrance, where the blast resistant gate supposed to be attached, is required to have 2600 mm clear height and 4100 mm clear width. These dimensions are appropriate for the entry of small to medium-size vehicles in addition to a pedestrian lane on one side.

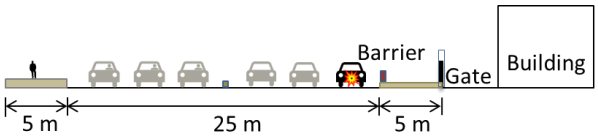

Figure 1: Blast scene

The mass of explosive material is assumed to be not exceeding 100 kg of TNT, or its equivalent mass of other explosive materials. Using ConWep, this mass, in combination with the 5m minimum stand-off distance, lead to approximately 6.6 MPa (66 bar) of pressure on the front plate of the targeted gate. This high loading is usually sustained by heavy gates of thick steel plates or composite concrete-steel materials.

The total dimensions of the sliding steel gate are 3000 mm high and 4500 mm wide (providing 200 mm of bearing surface on the supports and satisfying the clear opening requirement mentioned previously). The structure of the gate consists of 10 rectangular steel hollow sections of 180x100x10 mm welded to a front and a back steel plate of 10 mm thick each. The total thickness of the gate is 200 mm. Front, top and side views of the gate are shown in Figure 2. Weldox 460E steel material has been used for both the plates and the hollow sections due to its high strength and ductility.

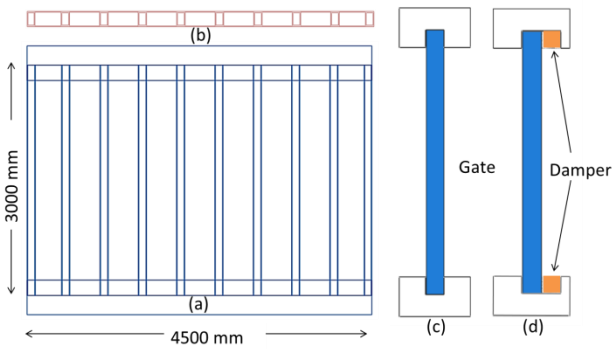

Figure 2: Front (a), top (b) and side views of the gate structure without damper (c) and with dampers (d)

*This study is part of an on-going PhD research (2014-2018), in the field of blast absorbing damping systems.

The energy absorber used in this study is an auxetic structure of re-entrant topology. Figure 3 shows the auxetic specimen and cell dimensions. The specimen consists of 27 cells in x-direction and 23 cells in the y-direction. The damper is 205 mm wide, 199.18 mm high and 4500 mm long. The cell wall thickness was set initially as 1 mm, and then reduced to 0.5 mm to examine the effect of such a change on the damper deformation and gate performance. The material used is Aluminium AA5083-H116.

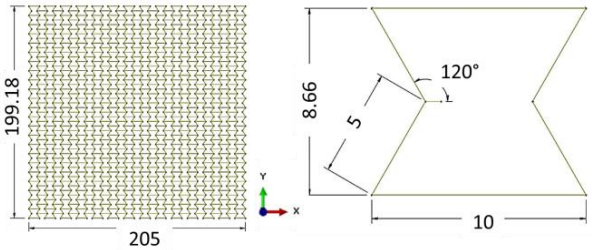

Figure 3: Re-entrant auxetic structure and cell dimensions (mm)

3. Numerical Modelling

The numerical analysis was conducted using Abaqus/Explicit solver. The gate was modelled as a solid part, with homogenous steel material that has elasto-plastic properties with Johnson-Cook model for strain hardening and damage initiation. A 3D explicit 8-node linear brick element has been used with 10 mm mesh size. In terms of the auxetic damper, it has been modelled as a shell part, with homogenous aluminium material that has elasto-plastic model with Johnson-Cook model for strain hardening. An explicit linear 2-node doubly curved shell element has been used with 5 mm mesh size. Material parameters are listed in Table 1. No boundary conditions were specified for the gate; instead, the gate is supported by two analytically rigid gutters. This in return, provided more realistic vibration and response for the gate as simply supported structure on long opposite sides, and free on short sides.

Table 1: Steel and Aluminium material properties

Parameter		Weldox 460E Steel	Aluminium AA5083-H116
E	MPa	$200*10^3$	$70*10^3$
ν	-	0.33	0.3
ρ	t/mm^3	$7.85*10^{-9}$	$2.75*10^{-9}$
A	MPa	490	215
B	MPa	807	280
n	-	0.73	0.404
$\dot{p}_0.\dot{r}_0$	S^{-1}	$5*10^{-4}$	$1*10^{-3}$
C	-	0.0114	0.0085
D_c	-	0.3	-
p_d	-	0	-
C_p	$mm^2.K/S^2$	$452*10^6$	-
χ	-	0.9	-
α	K^{-1}	$1.1*10^{-5}$	-
T_m	K	1800	893
T_0	K	293	293
m	-	0.94	0.859
K	-	0.74	-
D_1	-	0.0705	-
D_2	-	1.732	-
D_3	-	-0.54	-
D_4	-	-0.015	-
D_5	-	0	-

4. Results and Discussion

HMH equivalent stress (Mises stress) for the gate without dampers, at peak response time (6 ms), exceeded the yield point of the material. In other words, the material was within the plastic range. Equipping the system with auxetic dampers of wall thickness t = 1 mm led to negligible improvement in the gate behaviour. This was due to the high stiffness of the dampers. However, reducing the thickness to 0.5 mm dropped the stresses in the gate to the elastic range (Figure 4).

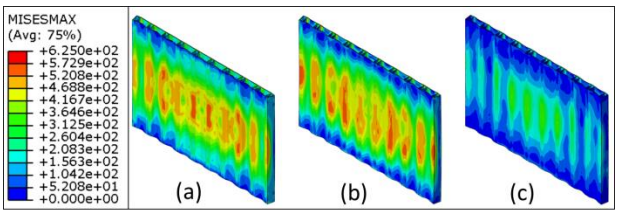

Figure 4: HMH equivalent stress (Mises stress) of the gate structure (a) without damper, (b) with damper t = 1 mm, and (c) with damper t = 0.5 mm

It is evident that the energy was dissipated through plastic deformation of the auxetic panel. Figure 5 below shows the top and side views of the deformed auxetic dampers, t = 1 mm, and t = 0.5 mm. The proposed auxetic damper presented in this study, with thin wall (t = 0.5 mm), can be a promising solution to maintain blast resistant gates operable after high intensity blast pressure of up to 6.6 MPa.

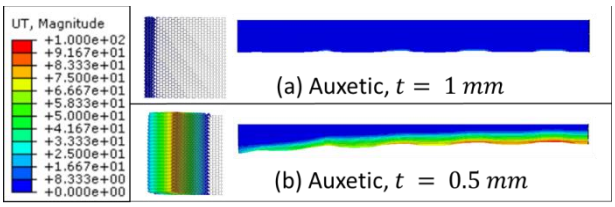

Figure 5: Top and side views of the deformed auxetic panels

5. Conclusion

Blast-induced response of a 3000x4500 mm steel gate was numerically assessed with and without auxetic dampers. The sliding gate was subjected to a blast of 100 kg TNT at 5m stand-off distance. Results revealed that the proposed sacrificial auxetic damper may maintain blast resistant gates operable after high intensity blast pressure of up to 6.6 MPa.

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